UNIVERSITEIT GENT
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Gesture in Samba

A cross-modal analysis of dance and music from the Afro-Brazilian culture

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Ghent University
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Department of Musicology

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Luiz Naveda

Thesis submitted to fulfill the requirements for the degree of
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Illustration:"Baiana em preto e vermelho" by Luiz Naveda.

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This thesis is dedicated to the memory of my sister
Liz Adhara Bavaresco de Naveda
(⋆ March 22, 1978 – † February 27, 2008)
whose love for dance and research still reverberates in my work.

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English summary

In this study, we focus on the relationships between music and dance in the Afro-Brazilian culture. We concentrate on the Afro-Brazilian *samba*, which belongs to the musical/choreographical panorama of the African diaspora and shares with the other pan-African cultures the tendency to integrate dance, music and social participation in every instantiation of the culture.

We approach samba from the viewpoint of *embodied cognition*, which basically assumes that the mind cannot be dissociated from the body. The idea that the body is not a simple vessel of the mind but contributes, molds and enacts the formation of meaning has a number of impacts on the study of dance and music. It extends the concept “mind” to tacit forms of knowledge such as dancing or moving, it sheds light on how the human body has influenced the human development, culture and reasoning. Moreover it enables the Western epistemology to approach forms of knowledge that have the body as the central mediator.

In the introduction of this work, we will demonstrate that few musicological approaches have been able discuss the relationship between music and dance in Afro-Brazilian culture. Although great part of the literature has stressed the importance of the “body” in the Afro-Brazilian musical culture, very few studies concentrated on the analysis of the dancing body, its movements and its gestural forms. How did dances connect with music? How do movements inform about the relation between music and dance?

The general concept of *gesture* is especially relevant in responding to these questions. Since the notion of embodiment blurs the limits between body and mind and thus, of perceiving and acting, it also unifies the activities of dancing and music making. Together, these experiences convey a sort of common gesture, or *cross-modal gesture*, which is acquired and performed through sound, movement, speech and other modalities. *Gesture* thus reflects this general element of the samba culture, which can be observed across different domains. In this study, we will investigate how this gesture in samba is modeled through sound and movement.

In the introduction of this work, we will demonstrate that the main methodological problems in the analysis of gesture in dance and music manifest themselves in questions related to experiments, algorithms and representations. In the course of the research we have gradually approached these problems, starting from a extensive review of the literature (Chapter 2), through the proposition of novel methods (Chapters 3, 4, 5 and 6) and the analysis of sets of recorded samba music (Chapter 6) and dance (Chapter 7).

In Chapter 3, we will introduce a computational heuristic that uses information

from musical meter to uncover patterns in dance gestures. Instead of looking at movement as a hermetic system or searching for single responses or parameters, we look for a summary of explanations in both music and dance domains. We implement a method based on Periodicity Transforms (Sethares & Staley, 1999) that uncovers a set of solutions for the gesture periodicities based on the interaction of movement with music. By rejecting single parameters and single modalities and by considering summaries of the relationships between music and dance we incorporate the tacit and explicit knowledge of dancers and musicians into a computational heuristics. In this study, we will also report on an experiment with 6 dances, which serve as proof of concept and which provides the definition of our initial hypotheses.

In Chapter 4 we will expand the epistemological and experimental scope of Chapter 3 and improve the framework of the heuristics for pattern detection. In this Chapter, we analyze different styles of popular dances (samba and Charleston) and different levels of expertise (teachers and students) by means of an improved version of the original algorithm introduced in Chapter 3. We apply these developments to motion capture data and introduced new representations that give rise to the concept of *basic gesture*. The *basic gesture* is a concept that was detached from the numerical method proposed in Chapter 3 and enriched with an epistemological background about cognition and embodiment. The idea behind the basic gesture approach is that it conveys a spatiotemporal reference frame on which dancers can reference their choreography. It can be seen as a form of mental representation, or as an imprint in the motor domains that is activated and dynamically transformed in the process of the rendition of gesture. Basic gestures are assumed to be formed by the incorporation of action-perception couplings between music and movement, or music and dance. This work on basic gestures formed the starting point for the development of the main conceptual elements that were used and complemented in further studies (e.g., Chapters 5 and 7).

Chapter 5 will complement the approach developed in Chapter 4 by introducing an approach that focuses on the space used by the gesture. The *Topological Gesture Analysis* (TGA) sees movement as qualities distributed in space. It borrows from the study of *topology* a geometry that is abstracted from shapes, distances and coordinates. It focuses on qualitative relationships and reasoning between music and space. We use this alternative geometry to qualify the space with meter-related cues, which provides a map of the organization of the space of the dances in relation to music. It assumes novel forms of interpreting gestures as topological relations and contributes with an additional set of cross-modal algorithms.

In the musical domain, a profuse bibliography in musicology provides support to the basic assumptions about samba music (e.g., rhythmic priority of samba music, connections of samba with African roots and its metric characteristics). However, other "movement inducing" characteristics of samba music such as the timing or the induction of "groove" are less clearly present in the literature. In Chapter 6, we realize several studies that approach timing and microtiming in samba music. In the first study, we investigate the patterns of microtiming deviations collected from a data-set of 106 excerpts of commercial samba music. We analyze how pattens of microtiming interact with the meter, spectrum and intensity in the auditory domain.

In the second study, we apply the same methodology to spontaneous vocalizations of samba rhythms recorded from musicians and non-musicians, in Brazil. In both experiments, we verify the same consistent profile of timing "deviations" and other tendencies of metric induction. Although these experiments marginally contribute to the main notion of embodiment, they unravel a new layer of rhythmic/timing structures, which cannot be analyzed from symbolic analysis of music (e.g., scores). In the third study, we reapply the methods for periodicity detection reported in Chapter 3 to auditory features extracted from the computational analysis of audio. These results reveal the ambiguous metric structure in samba music, and can be compared with the same type of analysis realized in the movement domain, in Chapter 7 (Section 7.8).

In Chapter 7, we will make use of all the developments realized in the previous chapters to investigate the characteristics samba dances in a data-set of dance recordings. We will also investigate how musical meter, gender, tempo and choreographic background affect these gestures. The methodology is applied to a data-set of 30 dances recorded with professional samba dancers. In the first part we process all excerpts with the basic gesture and TGA approaches. This results in a collection detailed analyses of dances, which exhibit a diverse panorama of styles. The basic gesture analyses were further correlated and discriminated using a number of methodologies that focused on the differences of gender, tempo and choreographic background.

Although our results offer examples of paradigmatic choreographies, the variability seen in the results of Chapter 7 reinforce the idea that samba dances are not represented by a single dance form nor by a single paradigmatic notion of choreography. The structure of samba dances seem to be primarily represented by a constant affirmation of "musical" meter contrasted with ambiguous metric relations in samba music. From this perspective, meter in samba appears to be much more a choreographic feature rather than a musical one.

The structure and enactment of meter in dance seems to be more detailed and contains much more parallel channels than its representation in music. The unambiguous properties of dance contrast with the ambiguity observed in the musical domain. The relationship between music and dance in samba seems to be regulated by a symbiotic relationship: while the two forms exhibit different metrical structures and different renditions at low-level information (signals) their interaction benefit from each other as a cultural system (high-level). The equilibrium between ambiguous and unambiguous content avoids both alienation (excess of ambiguous content) and monotony (excess of unambiguous content) in the context. Moreover, this complex mechanism of dependency seems to bind the choreographic structure of samba by making meaning in music dependent on dance context and participatory displays.

In Chapter 8 we will discuss the general aspects of our studies and discuss the main challenges, contributions, epistemological premises and future studies.

Nederlandse Samenvatting

In deze studie onderzoeken we de verbanden tussen muziek en dans binnen de Afro-Braziliaanse cultuur. Centraal staat de Afro-Braziliaanse *samba*, als voorbeeld van de diverse muziek- en dansculturen binnen de Afrikaanse diaspora. Typisch voor samba, en de meeste andere pan-Afrikaanse culturen, is de versmelting van dans, muziek en sociale participatie in één gentegreerd cultureel geheel.

We bestuderen samba vanuit het perspectief van de *lijfelijke cognitie*. De basisstelling van deze theorie is dat geest en lichaam niet gescheiden kunnen worden. Dit impliceert dat het lichaam niet enkel een recipiënt is voor de geest en volledig vanuit die geest bestuurd wordt, maar dat het lichaam ook de geest benvloedt en bijdraagt tot de vorming van betekenis. Deze visie heeft belangrijke implicaties voor de studie van dans en muziek. Zo wordt het domein dat traditioneel aan de “geest”wordt toebedeeld uitgebreid naar non-verbale vormen van kennis zoals dans of beweging. Deze visie laat ons toe om te bestuderen hoe het menselijk lichaam de menselijke ontwikkeling, psychologie, cultuur en redenering benvloedt. Zo geeft het de Westerse epistemologie ook de mogelijkheid om vormen van kennis te benaderen waarin het lichaam als centrale tussenschakel functioneert.

In de inleiding van deze thesis willen we aantonen dat er slechts weinig musicologisch werk is dat er in geslaagd is de lichamelijkheid van de Afro-Braziliaanse cultuurelementen te onderzoeken. Die lichamelijkheid uit zich in de dansmuziek, de bewegingen, de dansen zelf en hun verband met samba. Hoewel in een deel van de literatuur het belang van het “lichaam” in de Afro-Braziliaanse cultuur aan bod komt, concentreert de literatuur over samba zich vaak op de chronologische opeenvolging van muziekvormen. Kernvragen van dit doctoraat zijn daarentegen: Welke soort bewegingen zijn verbonden met sambamuziek? Hoe speelden de dansen in op de muziek? Op welke manier zeggen de bewegingen iets over de relatie tussen muziek en dans?

Het basisconcept *gesture* is zeer belangrijk met betrekking tot het beantwoorden van deze vragen. Het principe van “embodiment”doet de verschillen tussen ervaring van dansen en muziek, tussen actie en perceptie vervagen, en verenigt dus ook dans en muziek, net zoals dat in de Afro-Braziliaanse cultuur ervaren wordt. Aspecten van dans en muziek worden samengebracht binnen één gemeenschappelijke “gesture”, een *cross-modale gesture*, dat de basis vormt voor geluid, beweging, spraak en andere modaliteiten. *Gesture* weerspiegelt dus perfect de situatie binnen een cultuur als *samba*, dat zich zowel via beweging , als via tekst en muziek uitdrukt, en zowel vanuit de actie als vanuit de perceptie beleefd wordt. In deze studie zullen we nagaan hoe die “gesture”van de samba door middel van geluid en beweging gevormd wordt.

Verder willen we aantonen dat de belangrijkste methodologische problemen voor de analyse van "gesture" in dans en muziek zich manifesteren in vraagstellingen die betrekking hebben op experimenten, algoritmen en representaties. In het verdere verloop van dit doctoraat worden deze problemen stelselmatig aangepakt: aan de hand van een uitgebreid overzicht van de literatuur (Hoofdstuk 2), aan de hand van nieuwe methodes en verwerkingstechnieken (Hoofdstukken 3, 4, 5 en 6) en tenslotte aan de hand van de analyses van datareeksen voor muziek (Hoofdstuk 6) en dans (Hoofdstuk 7).

In Hoofdstuk 3 stellen we een computationele heuristiek voor die via het detecteren van metrische informatie uit de muziek, de verborgen patronen in de dansbeweging kan extraheren en classificeren. We beschouwen hierbij beweging niet als een gesloten systeem en gaan ook niet op zoek naar simpele, éénduidige relaties tussen specifieke aspecten van dans en muziek. We vertrekken van een opsomming van verschillende verklaringen, zowel in het domein van de muziek als in dat van de beweging, dit door middel van een niet-orthogonale methode, gebaseerd op "Periodicity Transforms" (Sethares & Staley, 1999). Via twee algoritmes (*Any-Route* en *Best-Route*) wordt een hele reeks periodieke signalen geëxtraheerd, gebaseerd op de interactie tussen dans en het muzikale metrum. Door eenvoudige parameters en modaliteiten te verwerpen en door de wederzijdse afhankelijkheid tussen muziek en dans te herkennen, integreren we de non-verbale en de expliciete kennis van dansers en muzikanten in deze heuristiek. De methode wordt toegepast in een studie van zes dansers, die ook aan de basis ligt van de precieze definitie van de initiële hypotheses.

In Hoofdstuk 4 zullen we dieper ingaan op de epistemologische, experimentele en methodologische basis, zoals die in Hoofdstuk 3 werden ontwikkeld. Hier wordt een verbetering van de vermeldde computationele heuristiek voorgesteld en wordt de analyse toegepast op twee voorbeelden van populaire dans (naast samba ook Charleston) en wordt de methode gebruikt om verschillende expertiseniveaus (leraren en studenten) te vergelijken. Als basismateriaal wordt hier gebruik gemaakt van data uit een "motion capture"-systeem. Door gebruik te maken van verschillende representaties werd het concept van de *basic gesture* ontwikkeld. Deze *basic gesture* kwam voort uit de strict computationele aanpak van Hoofdstuk 3 via het toevoegen van een epistemologische basis, gebaseerd op cognitie, beweging, bewegingsanalyse en 'embodiment'. Zo'n model kan beschouwd worden als een concrete voorstelling van de basisbeweging van repetitieve dans, maar ook als een mentale voorstelling. Het kan gezien worden als een patroon dat zowel is vastgelegd als een mentale representatie of als een lichamelijke beweging, waarbij beide geactiveerd worden wanneer het patroon in één van de domein opgeroepen wordt. Dit concept belichaamt dan ook de actie-perceptie koppeling tussen muziek en beweging. Het werk uit dit hoofdstuk ligt ook aan de basis voor de belangrijkste conceptuele elementen die verder in Hoofdstukken 5 en 7 zullen toegepast worden.

Hoofdstuk 5 vervolledigt de benadering die in Hoofdstuk 4 werd voorgesteld, via een benadering van de "gesture" waarin het gebruik van de ruimte centraal staat. De kern wordt hier gevormd door de methode van *Topological Gesture*

Analysis (TGA), waarin het kwalitatief gebruik van de ruimte via de beweging geanalyseerd wordt. Hierbij wordt gebruik gemaakt van ideeën uit de *topologie*: het abstraheren van vormen, afstanden en coördinaten, en de focus op kwalitatieve verbanden tussen muziek en ruimte. We gebruikten deze alternatieve geometrie om aspecten van het muzikale metrum in de ruimte te plaatsen, en op basis hiervan een kaart van de organisatie van het gebruik van de ruimte door de dansers te creëren, waarop hun relaties tot de muziek uitgetekend zijn. In de TGA benadering wordt de variabiliteit van de bewegingspatronen van de dansers uitgetekend en als topologische informatie gerepresenteerd . Er wordt een nieuwe benadering voor de interpretaties van gestures voorgesteld die toelaat om deze gestures als topologische relaties te interpreteren en er wordt een bijkomende set van cross-modale algoritmes ontwikkeld.

Binnen het muzikaal domein had het overzicht van de bibliografie met betrekking tot de sambamuziek al bijgedragen tot de fundamentele hypotheses voor het onderzoek naar muzikale "gestures" (bijv. de nadruk op het ritme, de Afrikaanse origine van samba en de impact daarvan op het metrum). Maar ook andere aspecten van het opwekken van beweging die geassocieerd worden met sambamuziek, zijn belangrijk in het kader van onderzoek. Zaken zoals *groove*, polymetriek, periodiciteit binnen het auditieve domein en "entrainment" van ritmische structuren komen vaak minder aan bod in wetenschappelijke teksten en experimenteel onderzoek. In Hoofdstuk 6 zullen we deze zaken nader bekijken aan de hand van 3 studies.

In de eerste studie bespreken we de afwijkingen in de microtiming in een collectie van 106 fragmenten van commerciële sambamuziek. We analyseren hoe specifieke patronen van microtiming samenhangen met de metrische structuur van de muziek, het timbrespectrum en de intensiteit in de muziek. Onze methodologie vertrekt van een auditief model dat de belangrijkste eigenschappen van het muzikale signaal detecteert. Om deze eigenschappen verder te analyseren combineren we methodes als piekdetectie en "machine learning" om zo patronen in de microtiming en de intensiteit, verspreid over het spectrum en de verschillende metrische niveaus, te kunnen clusteren. In de tweede studie passen we dezelfde methodologie toe op opnames van spontane vocalisaties van samba ritmes door muzikanten en niet-muzikanten (amateurs). In beide studies vonden we een soortgelijk gebruik van microtiming, naast andere tekenen van metrische inductie. Hoewel deze experimenten maar weinig bijdroegen tot de fundamentele vraagstelling omtrent embodiment, onthullen ze wel de onderliggende eigenschappen van ritme/tijd die minder duidelijk tot uiting komen in symbolische voorstellingen van muziek zoals in partituren. De reproductie van de patronen van microtiming uit de muziek, via de vocalisaties, bevestigt het belang van de eenheid tussen perceptie en actie in de sambacultuur.

In de derde studie rond muziekanalyse, pasten we opnieuw de methodes voor "periodicity detection" (zie Hoofdstuk 3) toe, dit maal voor de analyse van onze data-set van commerciële sambaopnames. We gebruikten het reeds vermelde *Best-Route* om de eigenschappen van de muziek te bepalen via het gebruik van een auditief model. De resultaten tonen de ambiguteit van de ritmische periodiciteiten in sambamuziek aan. Deze analyse zal in Hoofdstuk 7 (Section 7.8) vergeleken worden met een soortgelijke analyse in het domein van de beweging.

In Hoofdstuk 7 willen we gebruik maken van alle methodes beschreven in de vorige hoofdstukken om de kenmerken van "gestures" in sambadans te omschrijven. We willen ook nagaan hoe aspecten als het muzikale metrum en tempo en het geslacht en de choreografische achtergrond van de dansers deze "gestures" benvloeden. De methodologie wordt toegepast op een verzameling van 30 dansen, uitgevoerd door professionele samba dansers, die geanalyseerd werden met de benaderingen van de "basic gestures" en de TGA. Dit leidde tot een gedetailleerde analyse van dansen voorgesteld als "gestural shapes" en topologieën. In de "basic gestureänalyses werd verder gezocht naar correlaties en verschillen, via een aantal methodes die een reeks van algemene trends, verschillen tussen choreografische modellen en potentiële invloeden van geslacht, tempo en choreografische achtergrond onthullen in de resultaten.

De brede waaier aan "gestures" beschreven in Hoofdstuk 7 overschaduwt elke poging om één model voor sambadans of -muziek te definiëren. Hoewel onze resultaten voorbeelden van paradigmatische choreografieën bieden, bevestigt de grote variabiliteit in de data het idee dat samba niet staat voor één enkele dansvorm noch voor één enkele paradigmatische opvatting van stijl of houding. De dansstructuur van samba is voornamelijk gekenmerkt door een constante articulatie van het basismetrum, dat in contrast staat met de ambigue metrische relaties in het ritme van de sambamuziek. Hiermee rekeninghoudend lijkt metrum in samba meer een choreografische eigenschap dan een muzikale.

De structuur en de belichaming van het metrum in de dans lijken gedetailleerder dan in de voorstelling van het metrum in de muziek en bevatten ook meer parallelle, synchrone kanalen. De éénduidigheid van de dans contrasteert sterk met de ambiguteit van de muziek. Daarom lijkt het of de relatie tussen muziek en dans in samba van een symbiotische aard is: ondanks het feit dat de twee vormen verschillende metrische structuren bevatten en andere low-level informatie (signalen) uitzendt, zorgt hun interactie ervoor dat ze elkaar aanvullen als een cultureel systeem (high-level). Het evenwicht tussen het ambigue en de niet-ambigue aspecten zorgt er voor dat zowel vervreemding (door een teveel aan ambiguteit) en monotonie (door een gebrek aan ambguteit) vermeden wordt. Dit complex mechanisme van wederzijdse afhankelijkheid bevestigt ook de choreografische en sociale structuur van samba omdat de muzikale betekenis afhankelijk is van de dans en de participatie van de verschillende individuen in de sambapraktijk.

In Hoofdstuk 7, tenslotte worden de algemene lijnen van het onderzoek besproken. De voornaamste veronderstellingen, bijdragen en uitdagingen van het onderzoek worden samengevat en conclusies worden daaruit afgeleid.

List of Publications

- Publications in peer-reviewed international journals

  - Naveda, L. and Leman, M. (2009). A Cross-modal Heuristic for Periodic Pattern Analysis of Samba Music and Dance. *Journal of New Music Research*, 38(3):255–283.
  - Naveda, L. & Leman, M. (2010). Naveda, L. and Leman, M. (2010). The spatiotemporal representation of dance and music gestures using Topological Gesture Analysis (TGA). *Music Perception*, 28(1):93–111
  - Leman, M. and Naveda, L. (2010). Basic Gestures as Spatiotemporal Reference Frames for Repetitive Dance/Music Patterns in Samba and Charleston. *Music Perception*, 28(1):71–91.

- In Preparation

  - Naveda, L., Gouyon, F., Guedes, C., Leman, M. (submitted). Microtiming in Samba Music.

- Publications in peer-reviewed international conferences

  - Naveda, L., Santana, I., and Leman, M. (2010). Space, music and body dynamics in three excerpts of dance improvisation. In *Proceedings of the Digital Resources for the Humanities and Arts - DRHA2010*. Brunel University.
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  - Lobato, J. a., Naveda, L., Gouyon, F., Leman, M., and Reis, J. a. P. (2010). Synthesis of Dancing Motions Based on a Compact Topological Representation of Dance Styles. In *IROS2010 - First IROS 2010 Workshop on Robots and Musical Expressions*, Taipei. IEEE/RSJ
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1
Introduction

1.1 Dance and music

Music has always been accompanied by movement of people. It is not difficult to imagine that this relationship evolved into forms of dance. Considering movement as a form of musically driven gesture raises the fascinating idea that dances are like dictionaries of primitive relationships between music and movement, between the necessity of moving and the act of listening. From this viewpoint, the original musical structure should be accessible somewhere in the gestural forms or choreographic structures.

Although this image of music "fossilized" in dance gestures offers a tempting hypothesis, it does not uncover the mechanism behind the relationship between movement and sound. It only reproduces a reductionist portrayal of dances subordinated to music, which does not explain the origin of this music and how it became entangled in the dance traditions. It reproduces a Cartesian division between music for the mind and dance for the body. If the musical mind were to reside in the body, where could the original mechanism of music be found?

In this study, we focus on how dance and music influence each other. We approach it from the viewpoint of *embodiment*[1], which assumes that the *mind* is not dissociated from the *body*. We focus on the Afro-Brazilian culture of *samba*, which belongs to the musical/choreographical culture of the African diaspora and shares with the other pan-African cultures the same tendency to systematically integrate

[1] See 1.4.1 for a wider discussion about *embodiment* and related topics.

dance, music and social participation in every instantiation of the culture. The so called "music" from the African diasporas is but one aspect of the indivisible experience in Afro-Brazilian culture, which includes not only music and dance but also participation of the audience, ritualistic forms, enaction of myths, and other modalities of cultural expression.

So far, the available conceptual and analytical tools to approach this sort of phenomenon are still to a large extent dependent on a hermetic and disembodied concept of "music". The problem is not in the limitation of forms of music representation (e.g., musical scores) but in a Western concept of music as a phenomenon that "only" manifest itself by means of sound (see discussion on Section 1.4) and may not be suitable to our objects of study. Musical cultures such as the Afro-Brazilian music cannot fit into a single sounding phenomenon isolated from the context, and are oversimplified if considered only as a collection of dissociated modalities (e.g., a collection of music, images, video, text and speeches). What sort of knowledge can be hidden behind the dynamic interaction between modalities?

We opted to investigate music and dance forms as a single phenomenon because in samba the concept of music cannot be separated from the concept of dance. Musicians and dancers enact music with their bodies and often share it with others in society. Music in a multi-modal context requires an approach to musicology that incorporates other methods and epistemologies. Combining different modalities such as music, movement, dance and cognition requires an unusual interdisciplinary effort and a careful handling of the inherent complexity of each area of inquiry. Handling complexity in different contexts requires methods that provide a common ground for comparison between modalities. It also requires a selection of relevant texts to which these methodologies can be applied and become meaningful in context.

Much of the work realized here is focused on sonic and kinesthetic "texts" of the samba culture. More specifically we focus on what quantitative information collected from sound informs about the dance and what information about movement informs about the music. However, two possible contradictions overshadow these ideas. First, the focus on only two modalities within the samba context contradicts the assumption of multi-modality, which may result in a narrowed framing of the phenomenon. Second, the focus on quantitative information suggests a kind of "objectification" or isolation of the dances, music and bodies from its original context.

Both concerns are pertinent and cannot be ignored. In one hand, dance and music do not encompass all dimensions of samba culture but are the strongest foundations of its cultural practices. Music and dance in samba are extensively analyzed in cultural studies but have not been studied with regard to sound and movement, whose interactions have not been studied in detail as well. Sound and movement are not simple modalities and impose certain limitations, considered here as necessary conditions for the realization of the study with the available resources. The focus on these two modalities does not exclude the interaction within a context although we assume the necessity of a viewpoint guided by quantitative information and empirical approaches. In the other hand, it is important to notice that a methodology based exclusively on the subjective or the qualitative aspect does not imply a comprehensive approach to cultural subjects, either. Superficial approaches based on subjective information may reflect an aversion towards the body as an object of study or as a source of knowledge. Concentration on purely subjective "texts" may reflect the division between mental (subjective) and physical production (objective) and it may support a Cartesian notion of knowledge of the *mind* as opposed (and superior) to the knowledge of the *body*. These and other related issues will be discussed in detail in Section 1.4.

In the next sections, we will introduce the problems and questions that motivated our work. In Section 1.2, we will introduce the main questions raised in this dissertation, followed by an account of our hypotheses and background knowledge that inspired our statements, in Section 1.3. In Section 1.4, we will make an overview of the conceptual background upon which our study was formulated, including how issues of embodiment, cognition and musicology oriented our methodological choices. In Section 1.5, we will describe the methodological foundations that supported our research and in Section 1.6, we will outline the research design and methodological steps that were followed in the series of studies presented in this thesis.

The social and historical problems that inspired this research are presented in detail in Chapter 2. In this chapter we show how the lack of embodied approaches to the Afro-Brazilian music and dance lead to the problems specified in Section 1.2. The significant methodological developments realized in the course of our studies will be reported in Chapter 3, Chapter 4 and Chapter 5. The main experiments with data-sets will be described and discussed in Chapter 6 and Chapter 7. In Chapter 8, we will discuss the main contributions and conclusions.

1.2 Definition of the problem

Portrayal of Afro-Brazilian dance, Brazil, 1880s:

> '*Three or four groups of dancers soon positioned themselves in the middle of the ring formed by their companions; the women moved rhythmically, waving their handkerschiefs and indulging in a strongly marked movement of the hips, while their black escorts revolved around them, jumping on one foot with the most ludicrous contortions, and the old musician went form group to group, speaking and singing while shaking his sticks with frenzy. He seemed by his words to want to provoke them to dance and make love. The onlookers accompanied the batuco with hand clapping that emphasized the rhythm in a strange way.*' (Fryer, 2000, p. 102)

Portrayal of Afro-Brazilian dance, Brazil, 1990s:

> *The dance is on a three-count right-left-right/left-right-left-but it also weights one count, either the first or the second triplet. It may accentuate or contradict the weighting of the triplets in the music. As one triplet is heavier, the step slides toward the first line of rapid sixteenth-notes. (...) Our frequent admonition - stop thinking and dance - isn't to say that the motion is unthinkable. It's to say that the body is capable of understanding more things at once than can be articulated in language. One has no choice but to think with the body.* (Browning, 1995, p. 13)

These two contrasting reports on different perceptions of Afro-Brazilian dance and music illustrate some of the problems that motivated our approach to Afro-Brazilian music. In the first portrayal, the 19^{th} century's French woman projects her astonishment and moral standpoints onto movements and sounds that she was unable to comprehend. The alienation resulted in a fantastical report and a framed description of a dance characterized by certains movements of the hips and "strange rhythms". In the second portrayal, Browning (1995) attempts to describe the gestures and the music of a 20^{th} century samba dance, a dance that she understands and experiences through her body. However, the articulation between gestures and music in the text becomes meaningless due to the linearity of the textual descriptions. The body seems to challenge the attempts to represent it.

These two examples demonstrate the major obstacles occurring in traditional approaches to the study of Afro-Brazilian music and dance: the reproduction of reports that reflect a Cartesian notion of body, the tendency to interpret dance-music relationships from documental sources and the absence of proper representations for dance and music. In contrast, the literature (in special cultural studies) shows plenty of phenomenological and historical parallelisms between dance and music styles and indications of the dependency between music and dance.

Epistemological and analytical tools are necessary in order to explore the relationship with dance more seriously. In the next sections, we will specify under which conditions this necessity forms the basic hypotheses of this thesis and how we opted for a more systemic approach to the analysis Afro-Brazilian samba music and dance.

Epistemological questions

The consequence of adopting a disembodied perspective on musical forms (detached from dance) reflects in the way knowledge about samba is registered, distributed and reproduced. The actual theory and models underlying the knowledge of music samba forms are somewhat affected by all its problems and questions, in different degrees.

The theories of embodied cognition and sciences of the mind provide a conceptual framework in which practices in Afro-Brazilian cultures can be studied from a more comprehensive viewpoint[2]. Considerations raised in modern epistemology have changed the way we face the analysis, performance and enactment of music styles and dance practices. They raise new questions about internal representation of knowledge, how knowledge is formally represented, and how different modalities will retain and enact knowledge.

- What are the common cognitive bases for an unified approach for music and dance?
- At which cognitive level do music and dance gestures share information?
- If dance and music interfere mutually, how is this process then internally represented?

Musicological questions

From a musicological point of view, the expanded notion of musical culture as a complex of sonic and kinesthetic texts covers a considerable gap between formal and tacit knowledge in the traditions of Afro-Brazilian samba. However, the lack of direct approaches to the dance gestures and its relations with sound in the literature still represent a challenge. These questions — the relationship between dance gestures, meter and rhythmic ambiguity in samba — configure the main problem of this study:

- What are the basic relations between music and dance forms in samba?

[2]See Section 1.4 for a review of these theories.

- To what extent and at which level do the dance forms contribute to music forms?
- How are metrical and rhythmic ambiguity connected with gestural content?

Methodological questions

All the issues concerning musicological and epistemological problems mentioned above have a strong impact on the methodological framework that will be carried out in this study. Methodologies that allow for capturing movement are relatively new as well as methods to represent, analyze and interpret the gestural content encoded in these movements. The main challenge resides in the necessity to process different representations of modalities (e.g., audio, movement recordings, information collected from questionnaires) as one single modality and to deliver representations as such. If the inclusion of gesture and movement analysis complements the actual knowledge of music, it also changes the methods that we use to analyze music. Methodological challenges faced in this study can be linked to but are not limited to the following basic questions:

- How to transform data in low-level forms into relevant synthetical information about dances and music?
- How to develop methods that do not threaten the dance-music ecology by isolating their modalities?
- How to represent dance and music in the same framework ?

1.3 Formulation of the main hypothesis

Background

Sodré (1979) and Browning (1995) are especially important in the development of the hypotheses in this study. Browning writes about the concept of the body as a "text" in Afro-Brazilian samba. She considers the body as cultural record keeping, the body as part of the reasoning, body as a vessel for the divine dances in Candomblé (see a definition of Candombé on page 26). Browning seems to see in the complexity of rhythm and especially in the absence of accentuation in the first beat[3], an impulse to fill in the "empty spaces" of samba music:

> "The body says what cannot be spoken. Musically this can be explained as syncopation. Samba is a polymeter, layered over a 2/4 structure. But the strong beat is suspended, the weak accentuated. This suspension

[3] See description of samba music in Section 2.3.1

> leaves the body with a hunger that can only be satisfied by filling the silence with motion. Samba, the dance, cannot exist without the suppression of a strong beat."(Browning, 1995, p. 9)

Browning emphasizes the function of the very low drum *surdo* (which means "deaf" in Portuguese) in stressing the beat and bar levels. The *surdo* is one of the few instruments in the modern samba percussion ensemble that has a function to emphasize *commetric* levels[4], such as beat and bar levels. However, the *surdo* has a low-frequency spectrum and it is often muted on the 1st beat:

> "The surdo is so extremely deep in tone, so very bass, that its effect is like a negative utterance. It seems in a sense to erase or negate that moment in sound. Samba as a rhythm not only suspends its downbeat through the clave, but even in its stressing of this beat it blacks it out. The accompanying dance can fill the gap with a strong step or can reinforce its dislocation with another kind of suspension. But marking the absense of the downbeat is another way of indicating it. However the samba is danced, *it is the suspension or silencing of a beat which provokes movement."*(Browning, 1995, p. 15)

Browning (1995) also offers a valuable description of the characteristics of the sacred dances in the Candomblé cults (in which she was initiated), in Bahia. Although Browning did not objectively compare the sacred dances with any aspect of the actual secular forms in samba, she clearly considered the background of the Candomblé traditions and its gestural repertoire as an important component in the genealogy of dance gestures in samba.

Sodré (1979) is much more emphatic in approaching the samba context through the lens of the African inheritance. In Sodré we found almost all elements that will be presented in our hypotheses — the idea of dynamic ambiguity in music, embodiment and dance — explained from both socio-historical and Afro-Brazilian mythological viewpoints. The explanation for the dance-music structure of samba by means of Afro-Brazilian myths is particularly interesting because it illustrates how African religious cosmology may have been reproduced in the Afro-Brazilian culture, and how it may have been re-enacted throughout the history and in the structure of samba dances:

> "In the traditional African culture, (...) the music is not considered an autonomous function, but a form beside others — dances, myths, tales, objects — responsible of igniting the process of interaction between men and the visible world (the *aiê* in nagô) and the invisible (the *orum*). The meaning of a musical piece must be pursued in the religious system

[4]See definition of the pairwise *commetric-contrametric* terminologies on page 30

> or in the systems of symbolic exchanges of the social group in focus. Moreover, the communication medium do not limit their selves to sound elements, they also involve the connection between music and other art forms, above all the dance. (...)
>
> The dance rhythm adds the space to the time by consequently searching for symmetries to which it does not feel obliged to in a Western musical form. In the black culture, however, the music/dance interdependence affects the formal structures of each other, in a way that the musical form can be elaborated in function of specific dance movements, as well as the dance can be conceived as a visual dimension of the musical form." (Sodré, 1979, p. 21-22)

Sodré also mentions an empty beat or rhythm or a missing beat that must be filled out by movement in space (Sodré, 1979, p. 11). However, the focus of Sodré is on the figure of *syncope* which slightly differs from what Browning (1995) focused on. The syncope, for Sodré, is a *third person*, a missing link that could explain the mobilizing power of black music in the Americas. This power is represented by *Exú*, a deity of pantheon of the Afro-Brazilian religious system which was often misunderstood as the Western conception of "devil". *Exú*, in the *nagô* system, is the principle of movement that gives individuality to the individual and allows for *speaking*. For Sodré, the mythological figure of *Exú* is powerful but latent. It is the impulse that leads to the body to look for what was missing (Sodré, 1979, p. 68).

Hypotheses

Our hypotheses try to identify the origins of the reported link between dance forms and gestures and music forms. We argue that *the cultural link between music and dance could be reinforced, produced or resulted from relationships found in the signals* that represent movement and sound. These relationships would convey a network of links that provoke interdependency, in which ambiguity and contrametricity in the musical text could only be solved by periodicity and redundancy found in dance. The absence of one of the elements, especially the lack of embodiment of dance structures, would cause alienation or ambiguity.

These ideas are not entirely unknown in the scientific literature and are probably part of common sense of musicians and dancers in samba culture. However, the novelty of our approaches lies in adopting a more systematic/systemic perspective on movement and sound. This perspective extends the topics that are originally discussed in the cultural studies (including ethnomusicology, sociology, anthropology) to the framework of perception and cognition, movement sciences and signal processing (see sections 1.4 and 1.5 for a detailed discussion).

Limitations of this study

The amplitude of the historical, cultural and geographical scopes of Afro-Brazilian culture of samba is almost unreachable from a strictly scientific viewpoint and certainly intractable from a computational viewpoint. The lack of standardized terminology, numerous sub-styles, different instantiations of dance gestures, music forms and the constant change of the lively culture of samba induce a level of variability that is incompatible with the available resources and methods.

Although a great level of variability is also present in any sub-style, we delimit the universe of this study to the instances of the *urban samba*, influenced by the *samba carioca* from Rio de Janeiro. This part of the samba culture has been incorporated in the Brazilian culture and institutions as the "national symbol" of Brazil since the 1930s. It shares some characteristics with other sub-styles and dialogues with the sub-style *samba-de-roda* (from Bahia region), as the main inductors of the general notion of samba style in Brazil.

Other styles under the cultural influence of Rio de Janeiro are the *samba-de-roda*, *pagode*, *partido-alto*, *samba-canção* and *samba-enredo*. The style of dance *samba-no-pé* can be accompanied by all the former styles of samba music. In this study, we concentrate on the *samba-no-pé* dance, which is performed as an individual dance in both improvisational and non-improvisational displays.

We will focus on low-level data arising from movement and audio recordings, collected from databases of music or dance recordings. Although we have made an effort to map out the state-of-the-art of the literature in the field of human sciences, the sociological, psychological, ethnomusicological viewpoints on samba will not configure central elements of our approaches. We will limit our discussion to the choreographical and musical phenomenon of the samba culture, adopting perspectives from cognition, embodiment theory, perception studies, sciences of mind, computational ethnomusicology, signal processing and movement studies.

1.4 Epistemological framework

In the next sections, we will show that the complex nature of relationships of the Afro-Brazilian culture with music, dance and the body represents a challenge to the current state-of-the-art methods and conceptual tools. The criticism concerning the lack of proper approaches to study the relationship between music and dance was not only addressed in the fields of Afro-Brazilian musicology (Sandroni, 2001; Moura, 2004), sociology (Carvalho, 2000, 2004), dance (Mariani, 1986; Browning, 1995), ethnography (Gerischer, 2006; Sandroni, 2004), but are also discussed in other areas of research that provided the epistemological background for this thesis.

Because of the inherent similarity between Afro-Brazilian and African cultural forms, the strong corpus of African studies formed an important reference in our studies. For instance, the problems faced by African researchers when representing music-dance, the notion and importance of dance in the African culture and the holistic view of the music-dance practices in African cosmology, can all be applied to the Afro-Brazilian culture with few alterations. Among the contribution of African studies, the pairwise concepts *commetric* and *contrametric* (Kolinski, 1973) seen in Section 2.3.1, the idea of *additive* and *divisive* rhythms (Jones, 1959), the notion of circularity and periodicity in African culture (Arom, 1984; Koetting, 2010; Stone, 1985) and the structure of participative practices (Chernoff, 1991; Stone, 1985) will have a special impact on our methods and assumptions.

Though the most important part of the ethnographical literature in dance and music discusses the musical-choreographical traditions found in Africa and African diaspora, a number of studies also detected similar concepts found in other cultural domains. Blom & Kvifte (1986) investigated the metrical interdependence between *Hardingfele* music and *gangar* dance in Norway. Similar contributions were made by Martin (1979) and Felfoldi (2001) in relation of East-European dances. Grau (1983) reported on the *yoi* traditions in Bathurst Isalands (North Australia), which involve dance, music, singing and rhythm characterization (if seen from a Western division of practices). In the *yoi* traditions, the concept of dance seem to be more frequently seen as a part of a bigger phenomenon than as an isolated phenomenon in itself. We share this same ethno-relativistic viewpoint, as precisely described in Grau :

> "What is universal, then, is some kind of special behaviour that we recognise as dance and that seems to occur in all human societies. One can say that 'dance' is universal but that the ethnosemantic domain of 'dance' does not exist in every society or at least is bounded differently in different societies. The distinction between dance and non-dance must be equivocal, because it depends upon culturally shaped as well as universally objective components. At this stage we do not know what these universally objective components are, but it is possible to find out the culturally relative answers by isolating the appropriate ethno-domains." (Grau, 1983, p. 32)

1.4.1 Embodiment and enactment

The need for a better formulation of a theory that could support the broad ethnosemantic domains in which music and dance are found seem to be partially met by the emergence of theories of *embodiment* and *enactment*. The idea that the body is not a simple vessel of the mind but contributes, molds and enacts the formation of meaning, has two consequences: (1) it extends the essence of the concept "mind" to the actions carried by the body but (2) it also raises body actions (often disregarded as simply unessential) to a new status within the models of human development, psychology, culture and reasoning. This does not mean that these activities were not important before but that they were not easily observable or categorized in Western sciences due to the lack of proper epistemological and methodological foundations.

The first notion of *embodied* knowledge in Western science emerged in the field of phenomenology (Merleau-Ponty et al., 1968; Merleau-Ponty, 1945) as an alternative to the Cartesian division mind-body. It evolved into the concept of *embodied cognition* or *embodied mind* (Lakoff & Johnson, 1980, 1999) based on a number of insights found in the cognitive sciences, linguistics, robotics, biology, among other fields. The understanding that this same “new” body interacts with its environment lead to the concept of *enactment* (Varela et al., 1991; Bruner, 1966, 1968). *Enactment* or *enactive knowledge* is acquired through the action of *doing*. It is organized through *multi-modal interfaces*, which are metaphors of interactive displays where this knowledge is exchanged between modalities such as the visible, the audible and other senses.

The ideas originating from the philosophy, phenomenology and cognition were soon incorporated into dance inquiry. Some authors stressed the necessity for a better understanding of kinesthetic texts on dance (Desmond, 1994, 2000; Hanna, 1987), better accounts of dance as cultural knowledge (Sklar, 1991) and better reports on how dance movements are loaded with inherent meanings, perceptions and relations with music.

The framework of the *embodied music cognition* (Leman, 2007a) reunites all these elements within the field of musical inquiry. By appropriating the notion of a body and mind as a single entity, all the issues that were present in the relation of music with body were brought at the foreground of the music research. The long perceived relation of the musicians with their bodies, their instrumental technique, their relation with dance and aspects of group playing could finally be allocated in a proper epistemological framework together with their musical intentions, experiences of meaning and senses of art forms. This change in the epistemological background of musical research just corresponded better to the experiences of musicians, dancers and listeners. Together with progresses made in signal processing and sensing technologies, the framework of embodied music cognition lead to new ways of thinking about the research and to applications of music research.

If the idea of embodiment could offer a better framing for the musician’s knowledge as a distinct group whose practices are rooted in the bodily actions, it could also formulate better frames of analysis for other cultural groups in which the body plays a central role. The accommodation of the theories from phenomenology and embodied cognition into music research is capable to better account for the gesture, dance and movement found in different “musical” cultures. Although one could say that the scientific method is still restricted by an ethnocentric view on knowledge (e.g., Sodré, 1979), the framework of embodied cognition conveys a sharper and discrete conceptual tool that is less prone to bias of ethnocentric assumptions because it assumes an ubiquitous reference in the human experience: the body. It facilitates the observation of the loop between perception and action (see Calvo-Merino et al., 2006; Gallese, 2001; Molnar-Szakacs & Overy, 2006; Phillips-Silver & Trainor, 2007), which is fundamental for the evolution of culture (Leman, 2007a).

1.4.2 Gesture

Parallel to the development of embodiment theory, a number of tendencies in music research in the first half of 20th century outlined the insights that would further be incorporated into philosophy and cognition. Inspired by the Gestalt school, Becking (1928) studied the idea of "basic gesture" starting from musical movements (conductor's movements) in the attempt to find invariants that could account for emotion, style and characteristics of the musical form . Together with Truslit (Truslit, 1938) and Sievers (Repp, 1993b), Becking's work reverberated into further ideas such as the "essentic" or "sentic" forms in Clynes (1995), the investigation of tempo variations in Todd et al. (1999) and Repp (1999, 2005, 2006), the emergence of the notion of *entrainment* as proposed by Clayton et al. (2004) and several other advances of music research(Styns et al., 2007; Wanderley et al., 2005a; Leman & Godøy, 2010; Li & Leman, 2007; Godøy, 2003). The concepts that started to be developed in Becking's "basic gestures" were further improved by the idea of *reference frames* (Brown et al., 2006; Gallagher et al., 1998; Leman, 2007a) and configure one of the pillars of the work described in Chapters 3 and 4.

The general concept of gesture is specially important within the framework of this thesis. We have seen that the concepts of embodiment and enactment blur the boundaries between dancing and making music, perceiving and acting, deploying meaning and enacting forms in art. From this perspective, the "samba matter", experienced as a "style" by the dancers, musicians and participants in the *roda-de-samba*[5] cannot be explained as simple dancing, playing, clapping-hand actions. They are experiences that re-enact in a sort of common gesture, acquired through the modalities of sound, movement, text and are then deployed again (or enacted) into any of these modalities. *Gesture* thus reflects this general idea of a paradigmatic complex loaded with cross-modal relationships.

A series of publications have been appropriating the concept of *gesture* for the study of music and musically related forms marked by movement behaviors. These authors have been proposed to adapt the notion of *gestures* as "visible actions as utterance" to a more specific concept of "musical gesture" or "expressive gesture" as discussed in many recent publications (e.g., Gritten & King, 2006; Godøy &

[5] See definitions and context of the *roda de samba* in Section 2.3.1

Leman, 2010; Camurri et al., 2004; Cadoz & Wanderley, 2000; Wanderley et al., 2005a).

Jensenius et al. (2010) argues that gestures can be considered from the viewpoint of *control*, *metaphors* and *communications*. *Control* gestures are used to manipulate things while *communication* gestures could be considered as mostly empty-hand signalizations. *Musical gestures* could be related to gestures as *metaphors* since they describe emergent qualities of musical sound. Jensenius et al. (2010) explicitly defines them "as an action pattern that produces music, is encoded in music, or is made in response to music". Gestures as *communication* gestures are linked to bodily actions such as the ones present in story-telling or related with facial expressions, frameworks of communication and non-verbal language. McNeill (1992)'s taxonomy of communication gestures recognizes five types of functions: (1) *iconics*, representing a concrete particular feature of an object; (2) *metaphorics*, which represents an abstract feature of the object, (3) *beats* that emphasizes stress or discontinuity of words, (4) *deitics*, which indicates regions or directions in a space, and (5) *emblems*, which are gestures defined as stereotypes (such as waving hands to say goodbye).

Further qualifications of gestures can be derived from its properties in space, time, dynamics or from its musical function. Musical functions can be divided into the categories *sound-producing*, *communicative*, *sound-facilitating* and *sound-accompanying* gestures (see Jensenius et al., 2010; Wanderley et al., 2005b; Cadoz & Wanderley, 2000, for complete definitions and examples). These concepts contribute to the panorama of musically related gestures by reuniting several dimensions of musical experience at a structural level of analysis, which allows for better targeting and control of musical devices, analysis and performance of music. However, they contain an inevitable hermeticism or over-specification of the idea of *musical gestures* as if they were exclusively subordinated to musical functions, which has closed the concept to mutual influences between music and dance. If the gestures that are relevant for the music are orbiting the function of music (music production, encoding or response), the musical gestures would never have evolved into dance styles *per se*, nor would dances offer guidance to the emergence of music.

The *expressive gesture* as proposed by Camurri et al. (2004) seems to be more comprehensive to the aspect of immersive and holistic integration of modalities. Although this was often demonstrated by Camurri and colleagues using state-of-the-art sensing devices and multi-modal environments for performance, the concept of *expressive gesture* is able to support many aspects of this sort of "universal [dance] behaviour" delineated in Grau (see page 10): the dance as a multi-textual or multi-modal facet of the human experience in community[6].

[6]Here we see the "community" as the context of performance in the Western concept: dancers, performers, musicians and audience in the same environment populated by different modalities. This is somehow similar to the concept of *first existence of dance*, in Hoerburger (1968).

The *expressive gesture* is responsible for the communication of *expressive content*: "aspects related to feelings, moods, affect, intensity of emotional experience" rather than subordinated to the sound. The key concept in the notion of *expressive gesture* is that it is formed by a multi-modal network, that it is not a class of experience, but an abstraction of the experience itself as composed by channels (the modalities in an enactive interface) and levels of information. It defines "gesture in terms of structural units that have internal consistency and are distinguished in time and quality from neighbouring units" (Camurri et al., 2004, p. 3). It permits an useful structuralist depiction of the holistic experience of dance as a network of data structures. But how can these structural units be studied?

Camurri et al. (2004) proposed a specific modeling of this structure, namely the "layered conceptual framework", reproduced in the Figure 1.1. In this schema we find a structure that explicitly maps the transformation of information according to different levels of meaning. This information can be abstracted using a numerical representation of data, processed using computational resources and linked with high-level concepts. This framework provided the basic map according to which the experiments in this study were realized. It permitted the development of ways to observe the transit between low-level information encoded in movement and sound and high level information, ultimately represented by the idea of "samba" as style.

Several other referential frameworks will closely accompany our approach to dance gestures and music. Due to the strong connection between rhythm, meter and dance forms in popular dance forms such as samba, issues of movement and synchronization (MacDougall & Moore, 2005; Van Noorden & Moelants, 1999; Styns et al., 2007) are specially relevant. Since the dance is contextualized in a space (which is not only a measurable empty entity but an environment in which the dancer establishes psychological references), we will explore the available representations of the body in space (Ghafouri & Lestienne, 2006; Gourtzelidis et al., 2001) and references of space (Hall, 1968; Caggiano et al., 2009; Previc, 1998). Our conceptual basis also borrows from robotics the idea that the morphology of the human body has an influence on the mind, many aspects of perception, action and embodiment (Pfeifer et al., 2006, 2007).

In the following section we present our methodological framework, which is a more practical reaction to the problems observed in Section 1.2 and the hypotheses proposed in Section 1.3.

1.5 Methodological framework

In the last section, we have seen that the concept of embodied cognition forms the basis for the epistemological background of this approach to samba culture. The concept of gesture specifies how we approach the instances of the culture in context — dances, musical excerpts, their elements, external and internal representations —

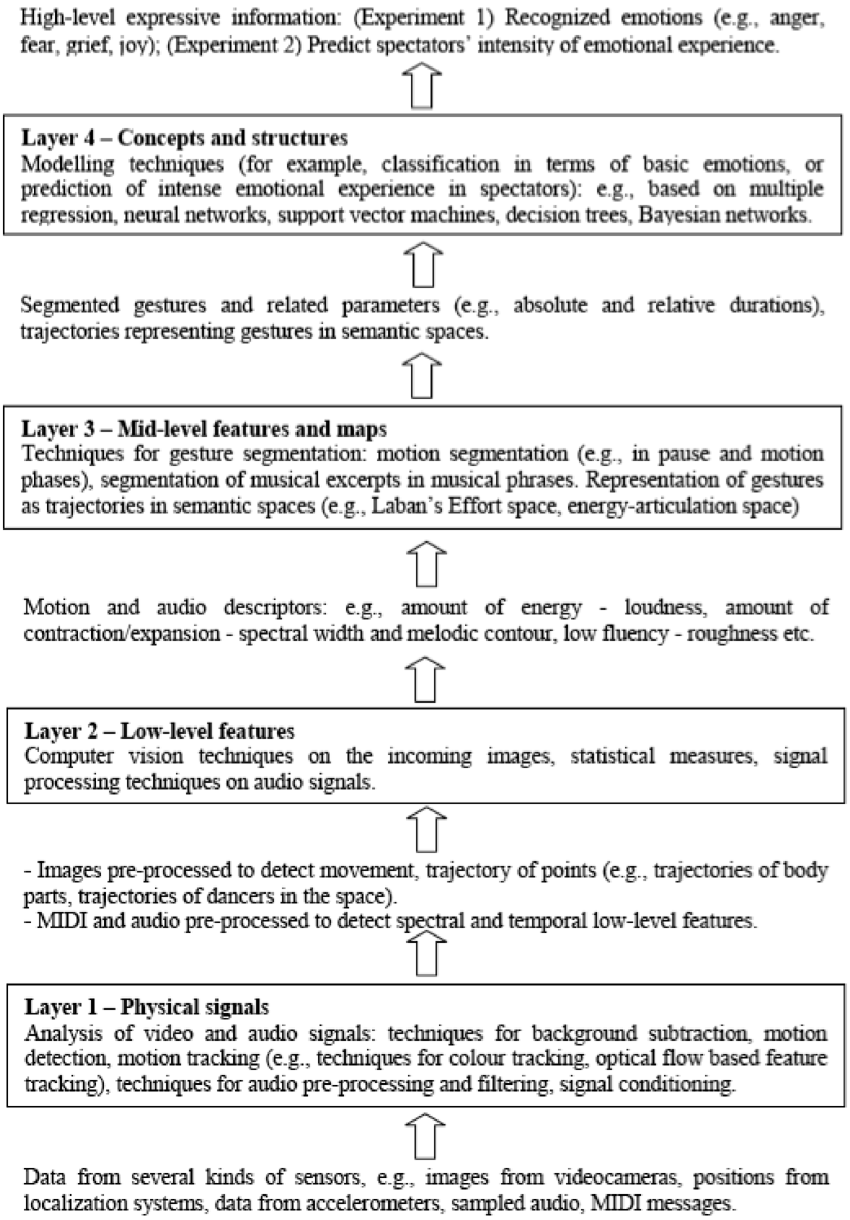

Figure 1.1: The layered conceptual framework as proposed in Camurri et al. (2004, p. 5)

and provides us with a collection of methods and hierarchical schema that help us unravel hidden structures in data and help transform it into representations.

The methodological background of this study is a combination of the techniques used in the gesture research together with a number of technical and theoretical tools, delineated in the processing of the data. Our challenges within this framework are divided into three forms of methodological demands: (1) *experimental*, (2) *algorithmic* and (3) *representational*. Each one of these demands is linked with specific developments described in the following sections.

1.5.1 Experimental demands

Most of our methods were based on empirical data collected from subjects. Experiments involving movement recordings are particularly problematic because the state-of-the-art technologies and procedures for movement recording are still obtrusive and time consuming. During our research, we have used video (Chapter 3), audio (Chapter 6) and MoCap (Chapters 4, 5 and 7) recordings realized in a laboratory, in combination with socio-cultural questionnaires and other data-sets. In order to preserve a homogeneous quality in the data-set, we rigorously implemented a series of premises in the organization of experimental recordings:

Subjects' vulnerability to performance or measurement bias In the experiments involving dance or performance, we opted to work with professionals (teachers, dance professionals etc.), who are supposed to be less biased towards laboratory conditions and the realization of proposed tasks. Experiments involving random subjects were always accompanied by measures of the performance effect (questionnaires) and attempts to reduce a bias towards measurement.

Quality and representation of the data-sets Experiments in which acculturation with samba culture is assumed beforehand were realized in Brazil or with acculturated Brazilians in other countries. The familiarity with Afro-Brazilian culture, the level of expertise and the level of experience with music or dance were assessed through questionnaires.

Quality of the records Most of the experiments were recorded using a set of state-of-the-art media recorders which include audio, video, movement and questionnaire data recorders. The synchronization, quality and data formats were previously reviewed and tested.

1.5.2 Algorithmic demands

The careful design of experiments and selection of data-sets provides a series of "enriched" digital objects that reflect a significant part of the gestural content of the dances and music. Different objects are *interfaced* with other modalities (e.g., motion capture recordings are synchronized with audio and video files) and keep the information necessary to represent the phenomenon. But how can these enriched networks of information be preserved against other dissociative processes in the course of the analysis?

Cross-modal heuristics

One of the main problems detected in the literature and the algorithms used in the analysis of multi-modal information is the lack of compromise between the rich multi-modal representations and the heuristics used in the analyses of these objects. For example, recordings of audio and video of a dance are commonly analyzed first as video/movement information and then as audio information. The results are also described as video and audio analyses and are discussed as music and movement, separately. How data-sets can be merged in the qualitative synthesis realized at each conceptual level of information (see Figure 1.1)? How intrinsic *cross-modal* connections can be retained at the algorithmic level?

Cross-modal processes have been observed in humans (Vroomen & de Gelder, 2000; Levitin, 2000; Fowler & Dekle, 1991), animals such as apes and monkeys (Davenport et al., 1973; Cowey & Weiskrantz, 1975) and further discussed in multimedia studies. However, very few examples of cross-modal algorithms have been applied to the analysis of sound and movement. In Camurri et al. (2006), for example, we find examples of how different modalities and different ways to process these modalities can be implemented into unified algorithms. In the developments described in Chapter 3, 4 and 5 we tried to cope with these limitations by creating a heuristics that shares multi-modal information and provide results that are mutually dependent. Cross-modal information applied to the analyses creates consistency (as proposed by Camurri et al., 2004, p. 3) in the gestural representation (see for example, Figure 3.13) and a better adaptation of the method to cross-modal contexts.

Modularity and data-flow

Modularity is also a concept rooted in the notion of ecologic perception and potencialized by the advances realized in digital technology for signal processing. We explicitly implement this concept in the organization of algorithms by organizing code and data-sets according to our frameworks *Samba library* (Naveda & Leman, 2010a) and the *DAS platform* (Naveda et al., 2010). These frameworks aim to reduce time and resources spent in development and diagnostics of cross-modal processes (collections of data streams such as video, audio and mocap data, linked with our recordings). They fundamentally allow re-using of data flows in a simple manner and also make the reproduction of the proof-of-concept of our analyses possible by other researchers. The *Samba library* and the *DAS* application are available for download on http://www.ipem.ugent.be.

The *Samba library* is a toolbox for Matlab platforms that contains the algorithms that were implemented in our research. The *DAS - Dance analysis suite* is an application for visualization and analysis of movement recordings (in special dance accompanied by music), available for Windows, Linux, Matlab and OSX platforms.

1.5.3 Representational demands

A considerable part of the methodology developed in this study deals with connecting different modalities and levels of information. However, making sense of the profuse information coming from these processes requires a huge effort with regards to the development of representations. Representations should reflect the same cross-modal ideas applied in the algorithms and meaningful information should be displayed in an explicit and syntactic way. How can we represent the data, the transformation of data and analyses in a meaningful way without dividing the information into modalities or losing numerical and statistical information?

Gesture representation

Representation of music and dance are very common concerns in the literature. However, the combination of multi-modal processes and representations in a meaningful way is not easily implemented. Figure 1.2 shows some examples of dance notation, representations of musical gestures and modern dance representations. They show a non-exhaustive panorama of different approaches to gestures accompanied by music.

The notational approach to dance is illustrated in Tomlinson (1735), who used projected score-like dance notation on the ground to indicate steps in court dances. Saint-Léon & Pappacena (2006) combined a musical score with dance notation, which detached the representation of the body from the spatial perspective. The well known *labanotation* (Laban, 1928; Laban & Ullmann, 1966) abstracted the body from its morphological representation in favor of more detail and fluency in the notation[7].

In modern dance representations derived from video analysis (Camurri et al., 2004) or 3D videogrametry representations (Palazzi et al., 2009) the space is again reintegrated in the representation. However, space can also be used to represent time such as the example provided by Jensenius (2006). The Becking curves (displayed in the bottom part of the figure) (Becking, 1928) introduced the concept of basic gesture, which was further developed by Alexander Truslit (Truslit, 1938). Truslit

[7]The same process of abstraction occurred in the transition of *tablature* notation, which depicts the strings of instruments, to the standardized five-line music score in the 11th century. It abstracted the strings in favor of more standardized and generalizable pitch reference.

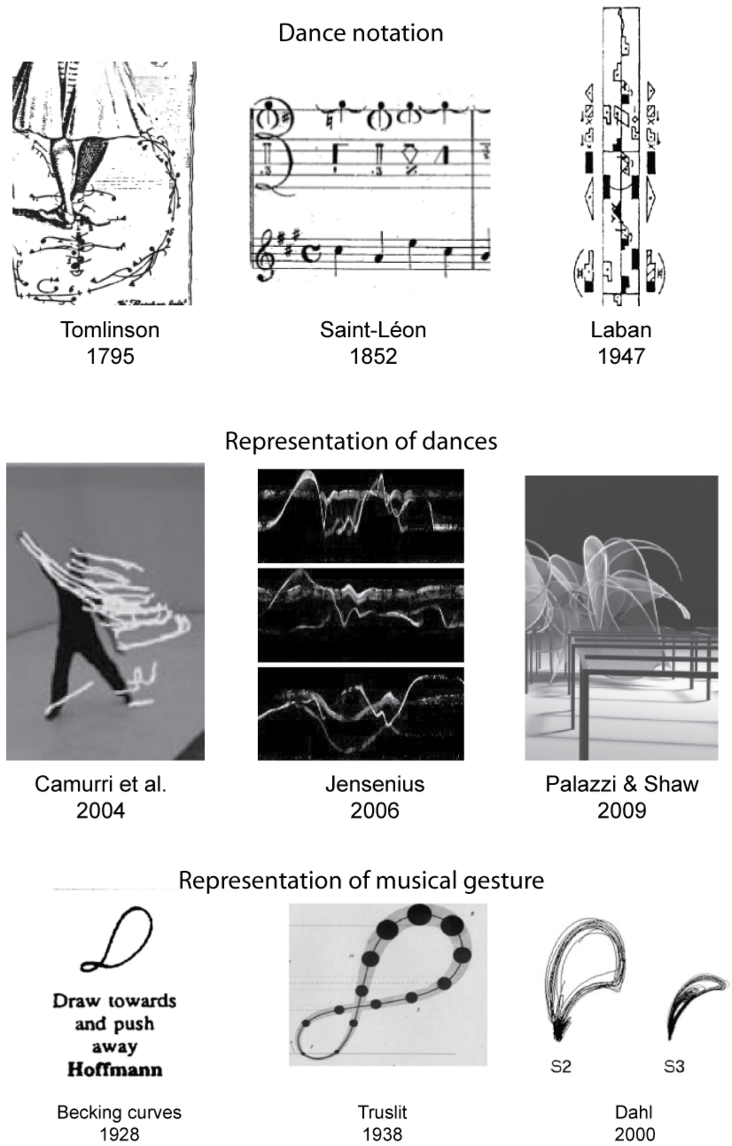

Figure 1.2: Panorama of the representation of musically driven gestures.

tried to incorporate musical features into the gestural pattern by managing the thickness of the line that describes the gesture in space. Dahl (2000) shows an analysis of drum players, based on data from a motion capture system (MoCap), which lead to a patterned accumulation of spatiotemporal curves that is reminiscent of the basic forms proposed by Becking, but based on quantitative data.

Relevant information concerning musical gestures illustrated by the examples of multi-modal representation seem to be encoded in the two main dimensions: space, which is considered the medium for the deployment of movement, and time, which is considered the medium for segmentation and synchronization of movement. The panorama shown in Figure 1.2 shows that the articulation of time and space in a single representation of gesture is not easily realized. These and other problems that affect the attempts to represent the gesture are summarized in the following elements:

Uni-modal representations The representation of gestures is often approached from either a spatial or a temporal viewpoint, as in frame-based video representations. Yet musical and dance gesture encompass a dynamic cross-modal link between several domains, such as movement, sound, language, and others.

Lack of representation of musical structure Musical structure is somewhat absent in gestural representation, as it focuses on body movement, rather than on musical structure.

Cartesian viewpoint The spatial reference is often based on the recording system, rather than on the subject that is moving. The representation is Cartesian, rather than body-centered.

Focus on low-level descriptions Most descriptions of gesture represent shape in relation to low-level movement cues such as position, velocity and acceleration and low-level music cues such as pitch and time positions.

Lack of information about variability The focus is often on invariant properties, whereas variability is frequently neglected.

In the course of this dissertation, we tried to develop new representations of gestures that take into account space, time and some of the problems verified before. The next section outline the steps of our developments.

1.6 Outline of the research

This research was realized in four phases with specific research designs, methodologies and focus. The first phase was dedicated to the review of the literature and the selection of methods. In the second phase, we developed new approaches that provide the basis for our methodology for dance analysis. In the third phase, we focused on musical features connected with induction of movement. Finally, in the fourth phase, we put the corpus of methodologies into practice by means of a large experiment with dancers.

Most of the phases are described in separate chapters and are connected with publications realized during the period. The main contributions and outline of publications are described in the following items:

1.6.1 Review of the literature (Chapters 1 and 2)

- Related publications:

  - Naveda, L. and Leman, M. (2008). Representation of Samba dance gestures, using a multi-modal analysis approach. In *Proceedings of the 5th Enactive International Conference – Enactive 08*, pages 68–74, Pisa. Edizione ETS.
  - Naveda, L. and Leman, M. (2008). Sonication of Samba dance using periodic pattern analysis. In Barbosa, A., editor, *Proceedings of the 4th International Conference on Digital Arts - Artech08*, pages 16–26, Porto. Universidade Católica Portuguesa.

In this phase, we carried out a systematic review of literature and several experimental pilots that covered an overview of methods and background of the study, including experimental designs and platforms for research and development. The end of this phase is marked by two publications that introduced our hypotheses and first results: Naveda & Leman (2008a) and Naveda & Leman (2008b)

In Naveda & Leman (2008a), we proposed two algorithms (*Any-Route* and *Best-Route*) based on the work of Sethares & Staley (1999) on Periodicity transforms, which allowed for novel analyses of periodicity of dance gestures using information from music. The results showed new forms of combining representation and approaching periodicity dance gestures from the viewpoint of musical meter.

In the study described in Naveda & Leman (2008b), we applied the heuristics reported in Naveda & Leman (2008a) to generate periodic onset and intensity patterns from dance gestures that were used to sonify a samba music from dance gestures. The musical sequences resulted from this process showed a potential closed-loop between dance gestures and movement descriptors. Rhythmic figures used in samba music could easily be found in the periodicity of movement descriptors.

1.6.2 Methods: dance analysis (Chapters 3, 4 and 5)

- Publications:

  - Naveda, L. and Leman, M. (2009). A Cross-modal Heuristic for Periodic Pattern Analysis of Samba Music and Dance. *Journal of New Music Research*, 38(3):255–283.

- Naveda, L. & Leman, M. (2010). Naveda, L. and Leman, M. (2010). The spatiotemporal representation of dance and music gestures using Topological Gesture Analysis (TGA). *Music Perception*, 28(1):93–111
- Leman, M. and Naveda, L. (2010). Basic Gestures as Spatiotemporal Reference Frames for Repetitive Dance/Music Patterns in Samba and Charleston. *Music Perception*, 28(1):71–91.

The lack of proper approaches for dance analysis was one of the main problems detected in the review of the literature. Consequently, in the second phase of the research, we concentrated on the analysis of dance gestures devoting special attention to periodicity, variability and representation of dance gestures found in popular dances. Naveda & Leman (2009), Leman & Naveda (2010) and Naveda & Leman (2010b) subsume the results and techniques developed in this phase.

Naveda & Leman (2009) and Leman & Naveda (2010) represent the main efforts made to tackle the analysis of periodicity in dance gestures. Naveda & Leman (2009) shows an original approach that is able to extract periodic gestures from the viewpoint of metrical engagement of the dancer. The study is based on 2-dimensional video data of 6 excerpts of samba dances. Leman & Naveda (2010) is based upon the heuristics introduced in Naveda & Leman (2009). It however includes further important developments and is based on data from motion capturing (3-dimensional) of samba and Charleston dances.

In Naveda & Leman (2010b) we tried to cope with the variability of the dance gestures. Instead of looking at the shape or trajectory of gestures in space, we looked at how dancers occupy and qualify spaces with musical features. Naveda & Leman (2010b) borrows from the general *topology* several elements that will permit abstraction of the artificial reference of 3-dimensional space imposed by the recordings and the concentration on qualitative relations of the dance with the space.

1.6.3 Methods: music analysis (Chapter 6)

- Publications:

  - Naveda, L., Leman, M., and Gouyon, F. (2009). Accessing structure of samba rhythms through cultural practices of vocal percussions. In Gouyon, F., Barbosa, A., and Serra, X., editors, 6th Sound and Music Computing Conference – SMC09, pages 259264, Portugal.
  - Naveda, L., Gouyon, F., Guedes, C., and Leman, M. (2009). Multidimensional microtiming in Samba music. In Pimenta, M., Keller, D., Faria, R., Queiroz, M., Ramalho, G., and Cabral, G., editors, *12th Brazilian Symposium on Computer Music*, Recife. SBCM

- Naveda, L., Gouyon, F., and Leman, M. (2010). Modeling musical structure from the audience: emergent rhythmic models from spontaneous vocalizations in samba culture. In *Proceedings of the 11th International conference on Music Perception and Cognition*, Seattle. University of Washington.

In this phase, we looked at elements of timing and enactment of musical characteristics of the samba style.

Timing or expressive timing is one of the musical characteristics often associated the feeling of *groove*, which is linked with the induction of movement and dance. In Naveda et al. (2009), we analyzed a database of samba music in order to look for patterns of microtiming deviations and intensities using machine learning methods.

Commercial recordings are examples of music characterized by expertise of musicians, recording techniques and other artifacts. The occurrence of patterns in commercial music does not guarantee that these patterns are embodied and represented in the ontology of the acculturated subject. How do we access these models? In Naveda et al. (2010) and Naveda et al. (2009) we approached this problem by using spontaneous vocalizations of samba rhythms. By using an original methodology that collects representations through a tacit form of vocal percussion in Brazil, we derived a model of timing enacted by subjects (musicians and non-musicians). The results show the same microtiming patterns observed in Naveda et al. (2009), which confirms a striking consistency of between stimuli and enacted patterns.

1.6.4 Experiment and results (Chapter 7)

- Results not yet published.

Thanks to the methodological background accumulated in the last studies, we were able to realize an experiment with 15 professional dancers in two different regions in Brazil. The dancers movements were recorded by means of a motion capture system and the results were processed using the methods developed in Leman & Naveda (2010); Naveda & Leman (2009, 2010b). The results (not yet published) are described in Chapter 6.

The results contributed to the description of gesture in popular dances and to a consistent analysis of the gestural forms in popular dance. The results also point at differences concerning genre and cultural background of the dancers and musical tempo.

2

Social and historical background of Samba

2.1 The context of samba culture

The genealogy of samba up to its first appearance as “samba music” in the beginning of 20th century is normally seen as a linear evolution of a variety of music genres which resulted in *urban samba* or the *samba carioca*[1], probably the best known sub-style of the samba culture[2]. The scenario of this evolution is often contextualized in the beginning of 20th century in Rio de Janeiro, although one cannot sub-estimate the contribution of Bahia’s influence to the consolidation of samba as Brazilian symbol and to the traditions in Rio de Janeiro[3].

The concurrent theories, names, places and dates, parallel histories and informal reports lead to a very confusing panorama of styles. The unavailability of sources of information about the musical practices in the 18th and 19th centuries in Brazil and the informality of the available reports contribute to the imprecise accounts of the

[1]“Carioca” is the demonym used for the city of Rio de Janeiro.

[2]This text will make use of numerous references to elements of samba that might refer to specific modalities or more general descriptions of context. The terminology must be taken with care and flexibility due to the open notion of modality of the cultural objects in Afro-Brazilian context. In the text, references such as “samba”, “samba context” and “samba culture” will indicate this broad multi-modal viewpoint formed by music, dances, texts, rituals, etc. When necessary, modalities will be specified as “samba music” or “samba dance”.

[3]The references to “Rio de Janeiro” indicate the city of Rio de Janeiro, capital of the Brazilian state with the same name. References to “Bahia” indicate the state of Bahia

context and the low representativity of the narratives (Ulhôa, 2007, discusses this problem in the narratives of Brazilian music in the 19th century). The elements of the musical scene in which the *samba carioca* emerged in the Rio de Janeiro's suburbs is not well documented and methods for registering and representing these stories, music and dances were unavailable at the time. The remaining historical narrative is based on musical scores, pictures and reports that represented the viewpoint of a few individuals who had the means to produce documents. These individuals were mostly part of a ruling class in the Brazil's post-slavery society, which was dominated by a rationalistic and Cartesian thinking aligned with European models and often isolated from the African and indigenous cultural matrices of Brazilian society. Nonetheless, a non-exhaustive overview of the knowledge about the context of samba culture may reveal elements that are relevant to understand the relation between dance and music presented in the this study. The next section describes the rise of the samba in the beginning of 20th century.

2.2 The invention of the modern samba

The recording of the song "Pelo Telefone"[4], in 1917, is widely considered as the first milestone in the modern samba. This is confirmed by the fact that "Pelo Telefone" was the first song to be officially registered and recorded as "samba" and by its enormous success that followed in Brazil. The song was registered at the National Library (Brazil) by Ernesto dos Santos (Donga) and Mauro de Almeida but it is a well-known fact that it resulted from a collective process of improvisation realized during the musical gatherings at the famous "Tia Ciata" house (Fryer, 2000; Sandroni, 2001; Moura, 2004; Sodré, 1979). Tia Ciata (aunt Ciata), or Hilária Batista de Almeida, was a well known hostess of musical parties in Rio de Janeiro. Born in Salvador (Bahia), Tia Ciata was a skilled sweet maker, dressmaker and an important worship assistant of Candomblé[5] cult ceremonies in Rio. Her house was a meeting point for musicians, composers and artists involved in the early samba culture in Rio de Janeiro during the 1910's. The emblematic description of the amalgam of activities and influences in her house — samba parties, Afro-Brazilian rituals and other musical gatherings — and the role of the participants in the posterior formulation of modern samba music in Brazil created the mythical image of the Tia Ciata's house as the "original" place of the *samba carioca*.

The disposition of the rooms inside the Tia Ciata's house is commonly used by scholars to illustrate the problematic process of assimilation of the African

[4] "By the telephone" (free translation by the author).

[5] Candomblé is an Afro-Brazilian religion practiced in Brazil. Together with Umbanda religion it forms the two most important ritualistic bases of samba culture, which are still very important in influential in Brazilian society (see Sandroni, 2004; Carvalho, 2000).

influences in the Rio de Janeiro's post-slavery society[6] and the strategies used by these actors to cope with this environment (Carvalho, 2000; Moura, 2004; Sandroni, 2001). The metaphor of a "filter", or a "cultural divider" (Sodré, 1979) between African influences and the white society is reflected in the disposition of rooms of the house and the kind of music, dances or personages circulating in each space during the musical gatherings.

During the parties, guests who were not fully "introduced" to the context were isolated in the visiting room, separated from the more acculturated side of the house. They were entertained with a slightly Africanized mixture of dances, music and social environment. This mixture more closely resembled to the European dances and was accompanied by *chorinhos* or *choros* (a very elaborated form of instrumental music derived from the *polca* and *lundu* forms) and other forms accepted by the society, and tolerated by the police[7].

In the dinner room, a selected group of "insiders" performed the improvisations that would lead to the 1917's samba. These improvisations were composed of an amalgam of musical and choreographic references coming from the "whitened" room and from the African influences in the intimate space of the house, all enacted in a circle-like display called "roda-de-samba". Samba was always associated with the idea of the *roda-de-samba* (ring of samba) which is a social and participative display performed by musicians, dancers and lookers-on organized in a circle or ring. In the *roda-de-samba* (brought by Tia Ciata as a participative *samba-rural* or *samba-de-umbigada* (Sandroni, 2001), from Bahia) dancers were accompanied by hand clapping, *pandeiro* and knifes on plates[8]. The few reports on the dances performed at Tia Ciata's house choreographies mention dances such as the *samba-no-pé* and the *miudinho* (described on page 37 and depicted on the Figures 2.8 and 2.9) were described. The *roda-de-samba* and its position between the "facade" and the "backyard" of the Afro-Brazilian culture will agglutinate the ideals and symbols of the samba that and will be further transformed into a national symbol during the 1930's (see Moura, 2004, for a more detailed account of the implications and importance of the *roda-de-samba* in the history of the samba).

Reports from participants of these parties (see Sandroni, 2001, p. 102, for a concise collection of examples) indicate that sambas or *batucadas* were realized in the *terreiro* (backyard). Descriptions of *batucada* at this time in Rio de Janeiro seem to designate a form of dance-game, similar to the *capoeira*, accompanied by a

[6]Slavery was officially ended in Brazil on May 13th of 1888, by a legal act of Isabel, Princess Imperial of Brazil. Brazil was the last nation in the Western world to abolish slavery.

[7]By the beginning of 20th century, samba traditions and Candombé rituals were strongly suppressed by authorities in Rio de Janeiro and Salvador. Tia Ciata (who was already initiated in Candombé in Salvador, Bahia) migrated to Rio de Janeiro after the repression of those religious manifestations in Salvador.

[8]Knifes and plates were very common accompaniments of samba in the beginning of 20th century. Any sort of cutlery could be rubbed against the plate to provoke a sound similar to the one performed by shakers or *caxixi's* in the modern samba.

circle of participants (Sandroni, 2001). The description of the *backyard* completes the metaphor that connects the spaces of the house — from interior to exterior — to the sociological ruptures faced by the actors from *intimate* to *public*, from *African* to *European* cultures. The move of samba from the "backyard" to the "living room" and its promotion as national symbol in the 1930s, seem to have been accompanied by analogous processes of assimilation that were not only reflected in socio-historical ruptures but also mirrored in musical/choreographic changes (see Sodré, 1979; Sandroni, 2001; Moura, 2004, for a detailed discussion about the socio-historical ruptures)

In this context where different forces of cultural expression (e.g., sacred, social, musical, choreographical driving forces) took part in improvisational practices, the so called "first samba" found a fixed instantiation that served as starting point for the documental part of the history of samba. The 1917's recording of "Pelo telefone" was only one choice among a number of versions that were submerged in the non-documented history of samba. How did these documented and not documented proto-models become a national symbol and how did they develop in terms of musical and choreographical characteristics? How did these characteristics become recognizable as samba?

2.3 A tentatively description of modern samba

Any attempt to define a model for samba will be obfuscated by the dynamics of the constant changes in Afro-Brazilian culture, in which concepts such as tradition, fixation, innovation and analysis must be interpreted with care. Modern samba is a lively culture. Unlike other traditional cultures, the samba still represents a strong force in both cultural and economical domains and interacts with the complexity of socio-cultural and socio-economical trends in Brazil.

Samba music is relatively well discussed and investigated in both academic and informal domains. It is supported by a strong tradition within cultural studies in Brazil and by a lively musical scene that re-flourished after the *pagode* revival in the 1990s (Galinsky, 1996)[9]. The characteristics of samba dances are much less documented. The discussion about samba dances takes place in dance schools and are based on instructional methods. We will try to raise a prototypical description of what is known as traditional characteristics in samba, with a limited focus on the urban *samba carioca*, which seem to dominate the concept of modern samba. However, we are aware of the diversity of influences that marked the evolution of samba until now, which will not be discussed this thesis. Instead, we will concentrate on the aspects of dance and music that support a broader notion of

[9]This contemporary scene involving the *samba carioca* is more concentrated in urban centers in the states of Rio de Janeiro, São Paulo, Minas Gerais and others.

style in the modern samba. We will specially concentrate on cues that indicate the aspects of sonic and kinesthetic texts found in the literature.

2.3.1 Samba music

Three characteristics described in both academic and instructional literature are widely attributed to samba music: samba has (1) a binary meter (2/4), (2) accentuated in the second beat and (3) a rhythmic texture characterized by syncopated rhythms (Chasteen, 1996; Mariani & Asante, 1998; Salazar, 1991; Sandroni, 2001; Moura, 2004, among others). Although the harmonic and melodic structure of samba music are based on the Western tonal model, it shows a strong tendency to rely on rhythmic priority. Sub-styles of samba are differentiated by a large range of variations such as musical structure, lyrics, geographical distribution, choreography, instrumentation and sometimes only differentiated by terminology (Fryer, 2000). For example, the *samba-carioca*, *samba-de-roda*, *pagode*, *partido-alto*, *samba-canção*, and *samba-enredo* are all known forms of samba music, which can be played as accompaniment for the *samba-no-pé* choreography. An example of typical Pagode/Partido-alto rhythmic patterns found in an ensemble was proposed by Moura (2004, p. 203) in Figure 2.1.

Figure 2.1: Rhythmic texture of the *Pagode* sub-style proposed in Moura (2004, p. 203). *Surdo* or *tantã* are mid-low instruments that fill the low-frequency range in samba instrumentation. *Ganzá* and *reco-reco* lines are high-pitched percussive lines. Other instruments play in the mid-high frequency textures, often marked by syncopated patterns.

Some of the canons of the samba style are exemplified in Figure 2.1. The *tantã*, a mid-bass drum that characterizes the *pagode* style, accentuates the second beat of the binary form, while the first beat is dumped with the hand or simply not stressed by the instruments. In the mid-frequency spectrum, *tamborims*, *cuíca* and *repinique* display an often improvisative mixture of syncopated rhythmic patterns. Instruments that play these patterns tend to exhibit a spectral signature concentrated on the mid-range frequencies, which gives a perceptual relevance to the syncopation lines. The *ganzá* and *reco-reco* play the highest part of the spectrum. They often display a rhythmic tessitura denoted by short and constant durations, also performed by the *pandeiro*. The example in Figure 2.2 shows how the models described in the score (Figure 2.1) match the texture of note attacks in an audio recording. In this representation derived from musical audio, an onset detection algorithm was used to detect sound onsets on 40 auditory channels distributed across the audible spectrum (for more details about the process, see Naveda & Leman, 2009). Figure 2.3 demonstrates the distribution of frequencies within the audible spectrum for four instruments used in samba. It shows how different percussion instruments of samba exhibit spectrum signatures that then to be discriminated by high-mid-low spectrum structure.

Samba music inherits the strong focus on syncopation from its African roots but also exhibits clear Western metrical characteristics such as the beat (*tactus*) and bar metric levels. The focus on syncopation is realized by means of syncopated or *contrametric*[10] rhythms in contrast to a non-syncopated or *commetric* background. This commetric background is often marked by a bass drum that stresses the pulse or beat (tactus) and a high-frequency instrument situated at the fastest metrical level (smallest subdivisions in 16^{th} notes). This later structure — a form of 16^{th} note constant train often performed by high-pitched instruments — seem to be quite present in all prototypical and illustrative examples of samba texture but is hardly mentioned in the literature about samba music. It seems not to have been defined in musicological literature before Bilmes (1993), who named it *tatum*. *Tatum*, *tactus* and *bar* metric levels are used to refer to these three important metrical levels that are present in the Western music and in samba music. Figure 2.4 illustrates the organization of the metric levels in a hierarchical structure.

Samba is frequently described as a *polymetric* form (Browning, 1995; Fryer, 2000), which means that it consists of different metrical layers having different periodic lengths and metrical phases. The metrical levels *bar*, *tactus* and *tatum* are made explicit through any form of periodicity in the rhythmic texture. However, syncopated lines can also induce other metrical layers by stressing other phases or hierarchies of meter. A prototypical model for this structure would be composed of bar and beat levels at the low-spectrum, syncopated patterns in the mid-spectrum and

[10]The *commetric* and *contrametric* concepts proposed by Kolinski (1973) are an attempt to avoid the notion of "deviation" in western metrical organization by classifying rhythms by its relation with subjacent metrical layer. The *commetric* concept conveys elements that affirm the metric structure (such as the beat or the bar level). On the contrary, *contrametric* coveys the elements that conflict with the metrical structure.

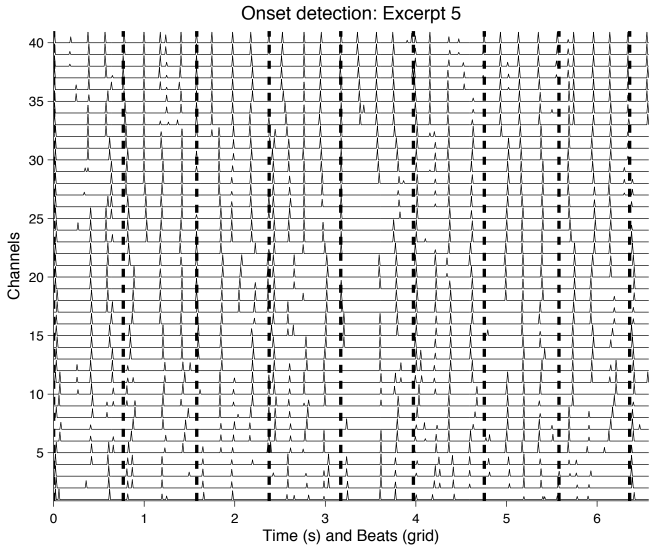

Figure 2.2: Onset image of 4 bars of the song "Ela veio do lado de lá" (Benito de Paula, 1975). Here the texture of onsets displays a discriminated layer in the higher channels (e.g., channels 35 to 40) forming a homogeneous 16^{th} note pattern (vertical traced lines indicate the beat points). In the lower channels (e.g., channels 1-5) the attacks of the low-frequency drum form a homogeneous beat periodic pattern. In the mid-frequency channels a complex mixture of rhythmic patterns takes place without obvious periodic patterns. This figure is explained in detail in the Chapter 3, or in Naveda & Leman (2009, p. 275).

the *tatum* level at the higher portions of the spectrum. In this hypothetical model, illustrated in Figure 2.5, mid-frequency instruments stress the contrametricity and rhythmic ambiguity while high- and low-frequency instruments provide a commetric background for rhythmic disambiguation.

It is interesting to note that the *surdo*, which is often played on the beat or bar (commetric), was not found in the samba ensemble before the 1930s (Sandroni, 2001, p.179). In addition, sound devices that mediated the impact of recordings and radio transmissions of samba before 1930's would not be able to reproduce the spectrum characteristics of such an instrument as well as the high-spectrum of the instruments played in the *tatum* layer. Whether this rhythmic environment shows a tendency towards a more or less ambiguous and complex rhythmic tessiture in the modern samba, is a question that will be discussed in the following sections of this dissertation. Authors like Browning (1995) and Sodré (1979) claim that this rhythmic signature was intentionally designed to provoke rhythmic ambiguity

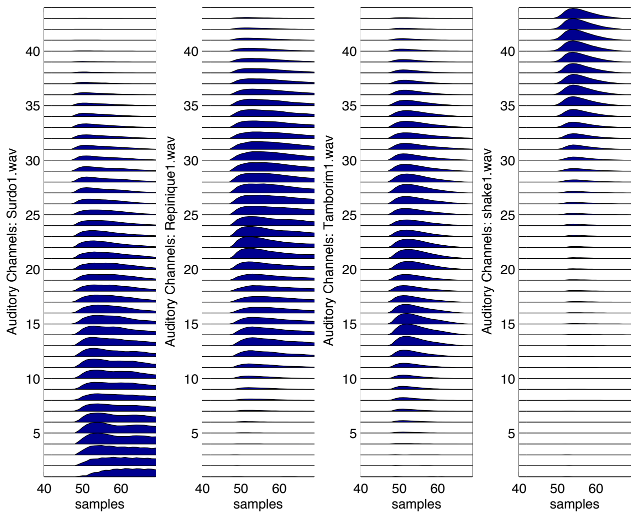

Figure 2.3: Frequency response of four samba instruments analyzed using an auditory model that outputs 44 frequency bands (Van Immerseel & Martens, 1992). Lower channels are related with low-frequencies, higher channels with higher frequencies. The response (curves) of the frequency bands indicate are analogous to a spectrum of the instrument sound. The spectral content of the surdo is quite prominent at low-frequencies while the spectrum of *repinique* and *tamborim* fills in the mid-frequency range. The spectrum of the shaker is concentrated in the higher part of the frequencies. Note that some overlap occurs in the mid- and high frequency channels.

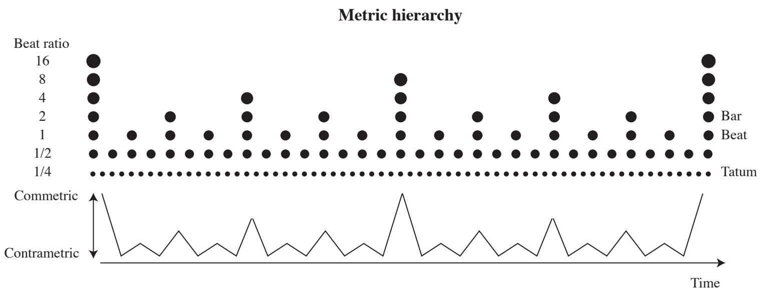

Figure 2.4: Hierarchical representation of the structure of meter (based on Lerdahl & Jackendoff, 1996) accompanied by a representation of the profile of commetricity and contrametricity.

(discussed in more detail in the Section 1.3).

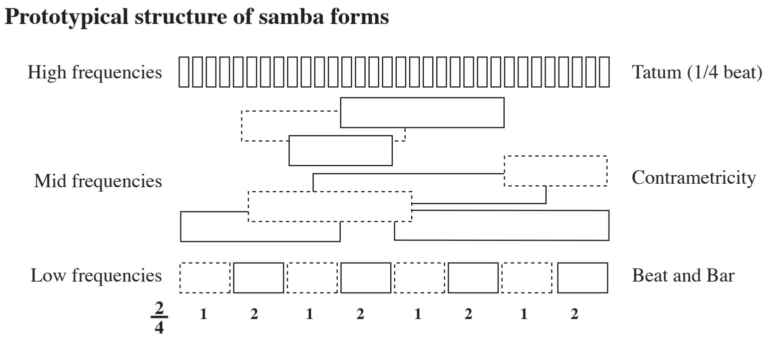

Figure 2.5: In this illustration we attempt to model the structure seen in Figure 2.2 and 2.1, according to a hierarchy of metrical levels. The commetric function is performed by high and low-frequency instruments, while the syncopation or contrametric counterpart is distributed in mid-frequency spectrum with a diverse display of metric levels and metric phases. Dashed lines indicate metric structures that can be hypothetically created by silence or alternative combinations of onsets and rhythmic phrases.

Rhythmic priority is claimed to perform a key function in the samba style and to incorporate a direct link with African influences (Sodré, 1979; Lima, 2005). A number of studies have systematically proposed hypotheses of rhythmic characteristics or even rhythmic figures that are supposed to be encoded in the rhythm structure of samba. The general figure of the "syncope" is the most common characterization (Sodré, 1979; Sandroni, 1996a). Figures such as the rhythmic variations of the "tresillo" (Sandroni, 2001), the "characteristic syncope" (Andrade, 1991), the "tamborim cycle" (Araújo, 1992, quoted in Sandroni 2001), the "samba rhythm necklace" (Toussaint, 2005), the "Angola/Zaire Sixteen-pulse Standard Pattern" (Kubik, 1979; Galinsky, 1996), "Samba patterns" (Demaine et al., 2009, p. 14-15) are other examples shown in Figure 2.6.

The focus on models such as the ones displayed in Figure 2.6 or the one proposed in Figure 2.5 offer several advantages and disadvantages. Models can be tested and provide a primary idea for discussion. Rhythmic figures proposed in Figure 2.6 can be further discussed and evaluated by its level of contrametricity (e.g., Sandroni, 2001), perception of syncopation (e.g., Fitch & Rosenfeld, 2007), similarity and distances in comparison with other rhythms (e.g., Toussaint, 2002, 2005). However, this approach also shows some disadvantages such as the lack of accounts of variability and the tendency to conceive music engagement as an activity based on (fixed) models. In addition, research in samba music often focuses

Name and pattern	*Sub-style of samba*	*Sources*
Characteristic syncope 	Samba, Lundu and maxixe	Sandroni (2001)
Estácio paradigm 	Samba	Sandroni (2001)
Mukuna 2 	Samba	Sandroni (2001)
Mukuna 1 	Samba	Sandroni (2001)
Tamborim Pattern 	Samba, Pagode	Sandroni (2001) Araujo(1992)
Angola/Zaire 16-pulse standard pattern 9 stroke verstion X . X . X . X X . X . X . X X .	Pagode and samba	Galinski (1996) Kubic (1979)
Angola/Zaire 16-pulse standard pattern 7 stroke verstion X . X . X . X . . X . X . X . .	Pagode and samba	Galinski (1996) Kubic (1979)
Classic Tamborim time-line X . X . X . X . . X . X . X . .	Partido-Alto	Galinski (1996)
Samba necklace 1 X . . X . X . X . . X . X . X .	Samba	Toussaint (2005)
Samba necklace 2 X . X . . X . X . X . . X . X .	Samba	Toussaint (2005)
Samba necklace 3 X . X X . X . X . X X . X . X .	Samba	Toussaint (2005)
Bossa-nova rhythm X . . X . . X . . X . . X . . .	Bossa-Nova	Toussaint (2005)

Figure 2.6: Table with examples of rhythmic models found in the literature. It does not configure an exhaustive overview of the proposed models but it demonstrates the focus on rhythmic formulas or "paradigms" of rhythms figures for the samba and sub-styles.

on percussive solo instruments or singing, whose models make up only a part of the context. Although modelling rhythm from rhythmic motives collected through subjective observation is inevitably biased by a variable level of interpretation and flexibility, this approach represents the state-of-the-art research in the field and should be supported by more research on motivic patterns, rhythm and metric analysis based on audio.

2.3.2 Samba dance

Very few scholars have attempted to describe the movement in samba dances. On one hand, it reflects the difficulty to find methodologies for movement and gesture analysis (hindered by the lack of widely accepted standards in dance notation). On another hand, it also demonstrates the self-sufficiency of the transmission of dance traditions. Although the literature of samba music does not rarely allude to the importance of dance, the contrast with the profuse documentation about samba music seems to indicate the effect that Desmond (1994, p. 36) described as "nearly unnoticed symbolic system". It refers to the idea that the body is so present in the life of a person (including scholars) that it becomes difficult to perceive it as a concrete text or carrier of information. This idea may also explain why music scholars so frequently mention the "dances", but rarely approach its components, movements, gestures in a systematic way[11].

So far, text-based descriptions of dance are the most common reports on samba dances found in the bibliography. Such descriptions tend to dis-articulate inherent complexity of the body engaged in dance (Ungvary et al., 1992; Desmond, 1994; Hanna et al., 1979; Calvert et al., 2005). They often lead to a puzzle of parallel movement descriptions arranged throughout the linear structure of text. Browning (1995) noted that any attempt to force textual descriptions leads to strange decompositions of the original dance, which are not satisfactory descriptions of the polymetric potential of the dancing body:

> "The dance is on a three-count right-left-right/left-right-left-but it also weights one count, either the first or the second triplet. It may accentuate or contradict the weighting of the triplets in the music. As one triplet is heavier, the step slides toward the first line of rapid sixteenth-notes. The stronger step gives almost two sixteenths to itself and hints at that doubleness by, in an instant, shifting the weight from the ball of the foot to the heel: a double articulation or flexing at the joint.(...) Our frequent admonition - stop thinking and dance - isn't to say that the motion is unthinkable. It's to say that the body is capable of understanding more things at once than can be articulated in language. One has no choice but to think with the body." (Browning, 1995, p. 13)

[11] Hanna (1987, p. 8) complains about the limited scope of dance descriptions in ethnographical records of dance: *"then they danced" is a common remark ad nauseam.*

Browning (1995) and Mariani (1986) undertake two rare attempts to represent and analyze the “text” that lies underneath the gestural content in samba. While Browning adopted an immersive perspective on samba culture by studying samba dances, Mariani tried to describe the gestures in samba by means of Laban’s analysis and notation (Laban, 1928; Laban & Ullmann, 1980; Laban & Lawrence, 1947; Laban & Ullmann, 1966). Mariani (1986, p. 336) provides a description of samba dance using a combination of text (quoted below) stick figures, displayed in Figure 2.7.

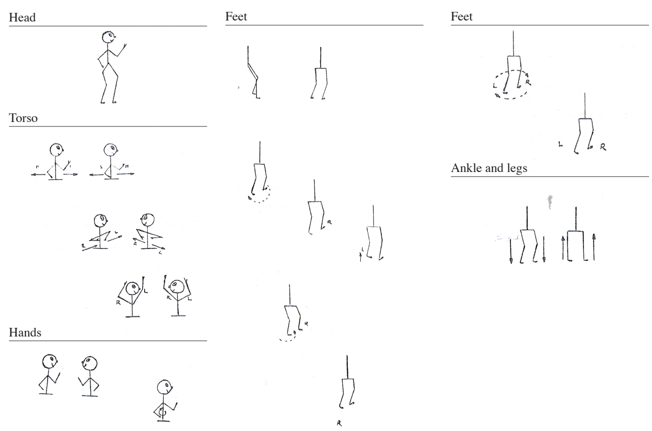

Figure 2.7: “General aspects of the samba movements” according to Mariani (1986).

> “HEAD tilts and sways, moving together with the other parts of the body, being affected by torso movements.
>
> ARMS are usually flexed and move in the Sagittal Plane (sometimes in Front[al] Plane), and diagonally. Sometimes, they are extended diagonally up, moving usually in the frontal Pl. They move constantly, accompanying the pulsating rhythm which is originated in the torso.
>
> TORSO is usually held vertically (sometimes moves slightly forward); side to side (medial rotation). The FEET move in a near reach space, usually in the Sagittal Pl. (Forward/Backward), simultaneously. But when the foot moves forward and touches the heel on the floor, back foot lifts off the floor and then steps on the ball of the foot. The actions

> of the feet are. R foot touches the floor forward on the heel, slightly turned in, and keeps a motion of turn out the leg, maintaining the axis of the R heel. Then it steps backward on the ball of the foot (weight on the ball) lifts slightly from the floor and touches the floor with the ball of the foot again. When the R steps backward, the L foot lifts and steps forward touching the floor with the heel. This action keeps repeating with the feet moving forward and backward. Also, the feet movements have other variations, such as direction/time, but the idea is as explained above.
>
> ANKLE and LEG actions: the bouncing actions is obtained by flexing and straightening the knees." (Mariani, 1986, p. 336)

Sometimes, images of dances within a context are able to provide better accounts of movement gestures. Figure 2.8 and Figure 2.9 show the *roda-de-samba* depicted by Heitor dos Prazeres, who was a painter, musician, composer and one of the protagonists of the early samba meetings in the the Tia Ciata's house. In these scenes, very important aspects of the *roda-de-samba* are represented: the circular display of the *roda-de-samba*, the non-existent division between dancers, musicians and participants (note that the unstable poses give an impression of movement the human figures), the portable instruments and the sense of social engagement. The dances depicted in Figure 2.8 and Figure 2.9 show other interesting choreographic differences. The women show poses that exhibit one foot raised in Figure 2.8 and both feet on the ground in Figure 2.9. The latter position of the feet combined with the hands placed on the hips refers to the *miudinho* choreography: this is a characteristic dance style derived from the *rural samba* and very closely resembles the actual *samba de roda* in Bahia.

If scholars have not yet developed methods to deal with the movement complexity of popular dances or forms to approach them in a systematic way, the market of instructional methods for dance has a long tradition in approaching it. Not only Brazil offers a very active market for dance, but also the international appeal of Latin dances has pushed forward the development of an industry of dance instruction, including methods, schools of dance, festivals and software. Unfortunately, instructional material often lacks proper referential bases or more formalized methodologies to report on dances. In the Chapters 3, 4 and 5 we will directly approach this issue with novel methodologies that try to encompass both musical interactions and movement representations.

2.4 Pre-history of samba

The linear evolution of the music styles reflected by the sequence *batuque* $\rightarrow$ *lundu* $\rightarrow$ *maxixe* $\rightarrow$ *samba* represents the most frequent hypothesis on the pre-

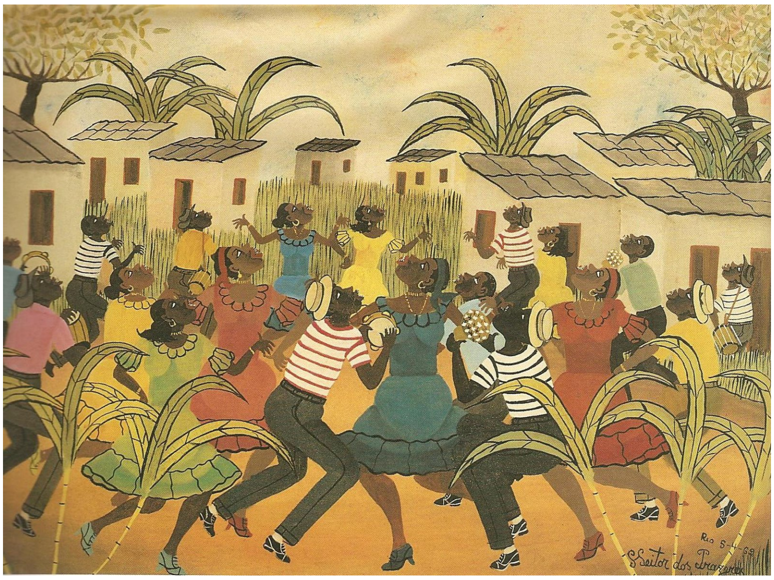

Figure 2.8: "Roda de Samba(1)", Heitor dos Prazeres, 1962.

history of samba music. A number of sources reproduce this simplistic genealogy that starts with a distant, poor documented *batuque* style and evolves in the relatively well documented *lundu* and *maxixe* styles (Sandroni, 2001; Castagna, 1990; Fryer, 2000). The latter two forms are represented in documental sources, such as scores and newspaper articles. Together with other characteristics, they denote both the assimilation of the African influence by the "documental side" of the history and the attempts to promote a de-Africanization of this influence (Lopes, 2005; Sandroni, 2001; Sodré, 1979; Moura, 2004, see).

Chasteen (1996) proposed a model that differs from the simple linear genealogy mentioned above because it focuses on the choreographical roots of modern samba and on the creative use of historical records. Figure 2.10 shows the schematic model proposed by Chasteen, which includes a three-pathway trajectory between *batuque* and samba. Although the model still considers the old forms of *batuque* the ultimate key between samba and what he called "African American choreographical matrix", it also includes the *congo* and the *batucada* elements parallel to the *lundu-maxixe* trajectory. *Congo*, also known as *Cucumby* or *Cucumbi*, is a dramatic dance that "enacted a drama involving gestures towards both African royalty and Christian iconography"(Chasteen, 1996, p.41), which is probably related to the *Congos* and *Congadas* (Fryer, 2000, p. 72). Detailed descriptions of the *Cucumbi* account for its incorporation in the carnival in Rio de Janeiro since 1830 (Fryer, 2000, p.73). *Batucadas* are described by Chasteen as *vigorous drumming*, which

Figure 2.9: ”Roda de Samba(2)” by Heitor dos Prazeres (date unknown).

conveys a quite limited definition of its characteristics and possible influences in the modern samba[12]. Before describing what is known about the old forms of *batuque*, lets investigate the most visible branch of the samba genealogy — the chain *batuque* → *lundu* → *maxixe*— starting with the closest link, the *maxixe* style, and finishing with the oldest link genre, the *batuque*.

Maxixe

Lundu and *maxixe* are considered by Chasteen to be the two missing links between *batuque* and samba. The main argument is that these two forms of dance and music were more frequently performed and more widely spread over Brazilian society than the *batuques* and *Cucumbis*. Indeed, the *lundu* (first references were found around 1780) was one of the most popular dances in Brazil during one century or at least one of the most documented dances and music during this period. Following the same path, *maxixe* substituted the *lundu* and started to appear as “national dance” from 1880’s to the beginning of 20th century. By the time the samba was being performed at the Tia Ciata’s house, the *maxixe* was still being danced in the Rio de Janeiro, New York, Paris and other cities. Figure 2.11 shows a sequence of

[12]See another definition of *batucadas* in Section 2.2

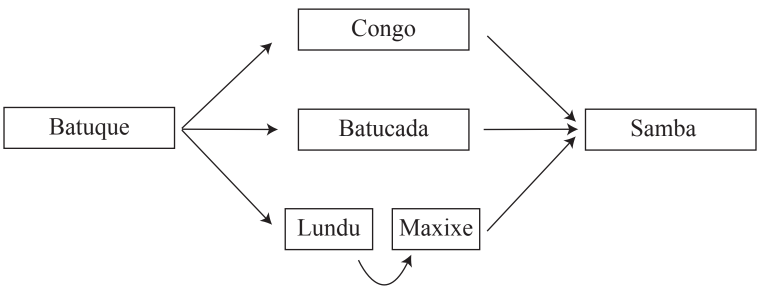

Figure 2.10: Alternative genealogy of samba proposed in Chasteen (1996).

photographs depicting the dance, found in an American dance instruction manual from 1914.

The *maxixe* was a social dance fundamentally different from samba, *lundu* and *batuque* forms by means of its interlaced couple dance display (*lundu* is also a couple dance, but the partners do not touch each other). The musical characteristics of the *maxixe* are associated with the *polca*, *lundu* and *tango* styles but are rarely specified in terms of musical characteristcs. Primary and secondary sources of reference often describe it as a "style of body movement", a "way to play music" or a "new way to dance the *lundu*" (Sandroni, 2001; Chasteen, 1996). Chasteen provides a detailed description of the movements of the *Maxixe*:

> "(...) maxixe was characterised choreographically by its requebros and reboleios, the same sinuous movements of the torso, hips, and legs that animated lundu and its cousins. As a couple dance, which is apparently how it started during the I870s, maxixe also involved very close contact between the bodies of the dancers, who sometimes pressed their foreheads together, their legs interlaced as in lambada, with full body contact at all points in between. Maxixe was not danced in the houses of 'decent' people." (Chasteen, 1996, p.39)

Sandroni (2001), Chasteen (1996) and other references establish connections between *maxixe* and *lundu* through the choreographical term *requebros*, which denotes specific movements of the hips and frequently refers to the movement of the female dancers. However, it seems odd not to relativize the importance and choreographic relevance of the term *requebros* in a 19th century society. Such

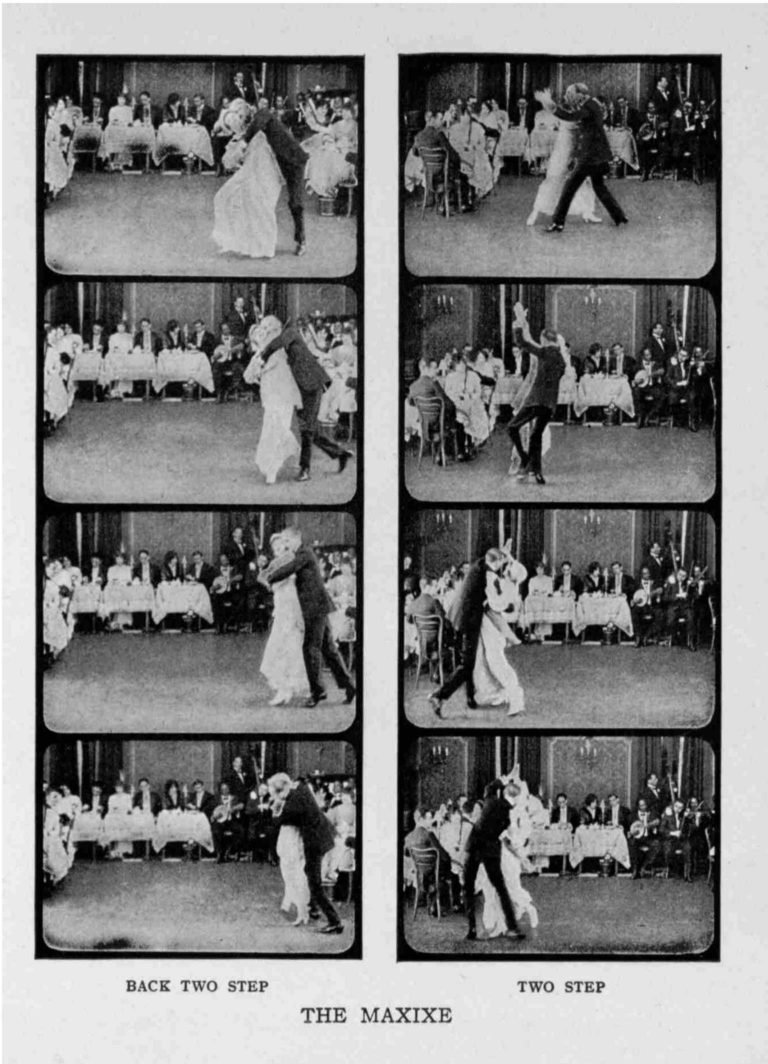

Figure 2.11: Sequence of *maxixe* poses illustrated in Castle & Castle (1914, p. 127).

considerations would probably be morally and socially biased. For instance, the reports on the *maxixe* that emerged in the middle of the 19th century are frequently seen from a male perspective. The content of these reports repeatedly involves sexist/racist portrayals of the "mulata" (a mulatto female) illustrated by descriptions of sensual movement of the hips (the "requebros") and depreciative comments on the vulgarity of the dances. The same white, mid-class males that found diversion in the small clubs in the Cidade Nova town where the *maxixe* started, contributed to spreading the vulgar connotation about genre (Chasteen, 1996, p. 39).

Maxixe had always been associated with symbols of racial mixing and Brazilian sensuality that, in combination with its national and international success, provoked a form of dissociation from the African origins (some authors argue that the dissolution of African origins was essential to its international appeal). One of the indications of this detachment is the elimination of the participants and open social display of the dance *lundu*, which seems to precede the *maxixe*. Some authors suggest that the XX-century's samba is a reaction to this dissociation, a sort of re-Africanization of the national dance, after the former appropriation of the African elements by a whitened mid-class by means of the *maxixe*.

Lundu

Sandroni (2001) identifies three different meanings for the word *lundu* in Brazil: a popular dance, a genre of ballroom song and a kind of popular folk song. The connection between the apparently popular dance *lundu* with African origins is considered an established common point between Brazilian musicologists. However, several authors stress that the basic forms of *lundu* might have been subjected to several other influences (Castagna, 1990) and were not performed by Africans or African decedents, but by "whites and pardos" (Castagna, 1990; Chasteen, 1996; Sandroni, 2001). Conversely, Chasteen (1996) suggests that a strong interest in polyrhythmic dances was already present in Brazil (imported from Portugal) before the *lundu* was introduced. Rugendas (1998, quoted in Castagna, 1990, p.13), in 1835, reported a direct link between *lundu* and Iberian dances such as the *flamenco* and *bolero*. Textual descriptions of the movements of the dance *lundu* are rare. A brief textual description of the *lundu* choreography is provided by Querino (1955, quoted by Andrade, 1989):

> "Two persons in the valse position would start the lundu. Then, they would give their hands; raise their arms in a gracious position, playing castanholas, continuing the dance detached from each other." (Querino, 1955)

Much of the appeal and popularity of the dance *lundu* is linked to its sensuous dance movements and the assimilation of African influences in the ballroom and concert music styles. Descriptions of the movements of *lundu* dance in the 18^{th} century are not so common and the few examples available report a dance influenced by the Iberian *fandango*, the *fofa* and *polca*. Rugendas, who provided a collection of valuable illustrations of life in Brazil during the 19^{th} century, also depicted a scene of the *lundu* dance in one of his illustrations (shown in Figure 2.12). Although the *lundu* was a couple dance it was danced in the presence of a circle of musicians and participants, like the *roda-de-samba* in the modern samba.

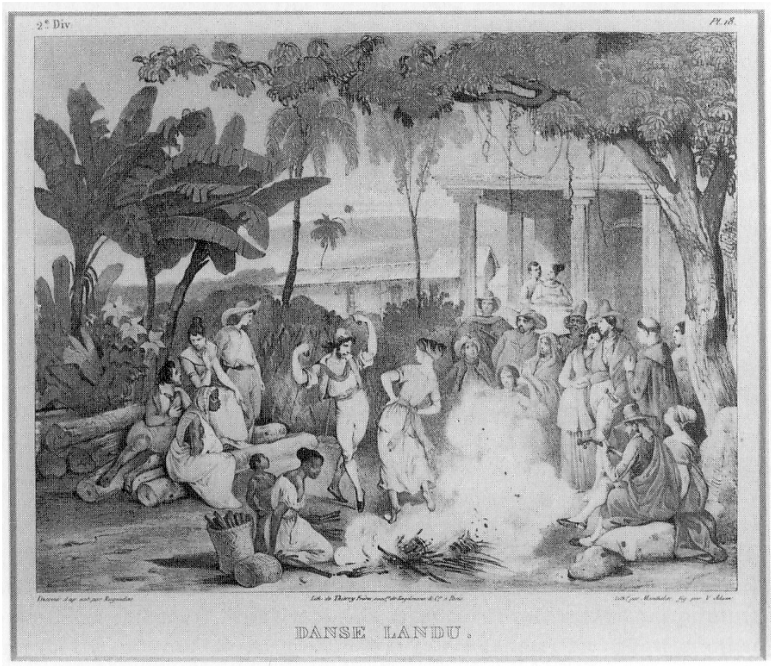

Figure 2.12: Lundu dance in 1820s, considered as Brazil's national dance at that time (Rugendas, Malerisch Reise in Brasilien). Source: Revista de História da Biblioteca Nacional, ano 1, n 8, fev/mar. 2006, as quoted in Fryer (2000).

Information about the structure of the *lundu* music seem to be richer than the information about the dance styles. By the time musical printing in Brazil started around 1830, the *lundu* and the *modinha* (another music genre always connected or confounded with *lundu*) started to develop into independent music forms (Sandroni, 2001, p. 40). The *lundu* and the *modinha* incorporated African influences, denoted by syncopated accompaniments and melodies, or more specifically by a recognizable level of contrametricity. Sandroni (2001, p. 40) emphasizes the occurrence of formulas such as the "characteristic syncope" (see Figure 2.6), seen by the author as a variation of the *tresillo* formula. Both syncopation and the "characteristic syncope" will be used in the 20th century to denote characteristics pertained to the modern samba. Sandroni (2001), Béhague (1968) and Andrade (1989) explored the classes and hierarchies of syncopation and the content of the lyrics (textual) that seem to characterize the forms of *lundu* and *modinhas*. According to Sandroni (2001, p.

48), syncopated figures appearing across bars were considered by Béhague (1968) and Andrade (1989) as more closely related to a popular Brazilian style. Sandroni (2001) rejects the concept of syncope in favor of the concepts *contrametricity* and *commetricity,* borrowed from Kolinski (1973) (explained on page 30). Figure 2.13 shows an example of a score of *lundu* music for piano where the "characteristic syncope" can be seen all over the first part of the accompaniment and in certain measures in the melodic line.

Figure 2.13: Score of the Lundu Assahy. Note that paradigmatic figures such as the "characteristic syncope" appear in the accompaniment and melody. Source: Biblioteca Nacional Digital do Brasil.

From a musicological viewpoint, the classification of the figures of syncope as something associated with "Brazil", "African" and "popular" marks the transformation of the rhythmic heritage of African influence into a new style that for the first time was denominated "Brazilian". From a choreographical viewpoint, the association of the "requebros" and "sinuous movements of the hips" with stereotypes of Brazilian and African identities introduced the myth of the "mulata". This reflects the start of a confusing political-social project that promoted racial mixing and sexist views on the female body and dance, which still permeates the notion of Brazilian identity (Browning, 1995). When considering lyrical content, the thematic focus change from "love" to "sexual" and "satiric" during the course of the 19^{th} century.

The characteristics attributed to the Lundu contributed to the ambiguous tendencies of cultural origins (Brazilian and African), metrics (contrametric and commetric), thematics (romantic love or sexual) and functions (concert or ballroom). Such ambiguity could not be fully understood from a Westernized perspective. The function and the presence of this ambiguity during the first cultural exchanges between African and Western world in Brazil are the main issues discussed in the reports about the *batuque*, in the next Section.

Batuque

The *batuque* is the most undocumented form of music and dance but at the same time also reflects the most general definition of choreographic, musical and religious expression with African origins in Brazil. The terminology *batuque* means literally "hammering" in Portuguese, but it can be use to refer to specific ceremonies, dances, percussive music, any sort of African dance, forms of *capoeira* and many others. It is certain that any form of *batuque* dance or music involves percussion accompaniment and the use of hand-clapping (Fryer, 2000, p. 95). We are especially interested in the forms of dance and music that could be more directly linked with the genealogy of samba.

Several reports about the existence of *batuques* are found in registers of public repression made by police or government, in several Brazilian towns, during the first half of 19th century. A number of bans and penalties for drumming in the cities were imposed in several places for different reasons. Other references link the term *batuque* to a secular dance from the Kongo-Angola, a dance *batuco* in Angola, *batchuk* dance in Mozambique, among other links with linguistic similarities (Fryer, 2000).

The contact between foreigner visitors and the *batuque* engendered a number of reports on dances that were referred to as *baduca* or *baducca*. Rugendas, who illustrated the dance *lundu* in Figure 2.12 also provides an illustration of the dance *batuca*, shown in Figure 2.14. In this figure, we observe a male dancer surrounded by a semi-circle of participants that clap their hands and seem to engage in accompanying movements as well (unstable positions of the torso and feet denote tendencies of movements). Figure 2.15 shows another a possible description of the *batuque* form, depicted by Spix and Matius in 1823.

These visitors, mostly European or North-American males, left some valuable descriptions of the *batuque* music and dances of the 19th century, which are based upon a strong sense of exoticism and novelty. These external viewpoints are also characterized by surprise and moral embarrassment, which are reflected by the use of depreciative terms such as "indecent", "lascive" but also terms such as "passionate" or "interesting". In a rare example of a woman's perspective on these dances, we report here a description made by a French woman who travelled

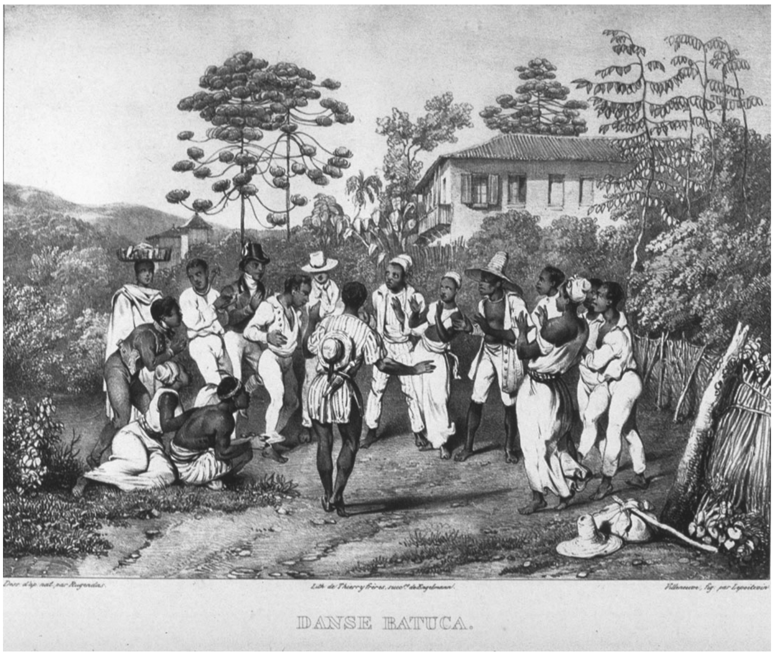

Figure 2.14: *Danse Batuca* portrayed by Rugendas in 1820s. (Rugendas, Malerisch Reise in Brasilien).

through Brazil in the1880s, quoted in Fryer (2000, p. 102):

> "Three or four groups of dancers soon positioned themselves in the middle of the ring formed by their companions; the women moved rhythmically, waving their handkerschiefs and indulging in a strongly marked movement of the hips, while their black escorts revolved around them, jumping on one foot with the most ludicrous contortions, and the old musician went form group to group, speaking and singing while shaking his sticks with frenzy. He seemed by his words to want to provoke them to dance and make love. The onlookers accompanied the *batuco* with hand clapping that emphasized the rhythm in a strange way." (Fryer, 2000, p. 102)

Several characteristics make this report very particular and valuable. Reports from the perspective of a European woman in the 19th century are as rare as reports on the male and female dance movements. For the first time an allusion to the figure of male dancers is made in a report. Although the available iconography has often displayed male dancers (see, for example Figures 2.8, 2.9, 2.11, 2.12, 2.14 and 2.15), they are curiously not mentioned in textual/verbal testimonies at that time.

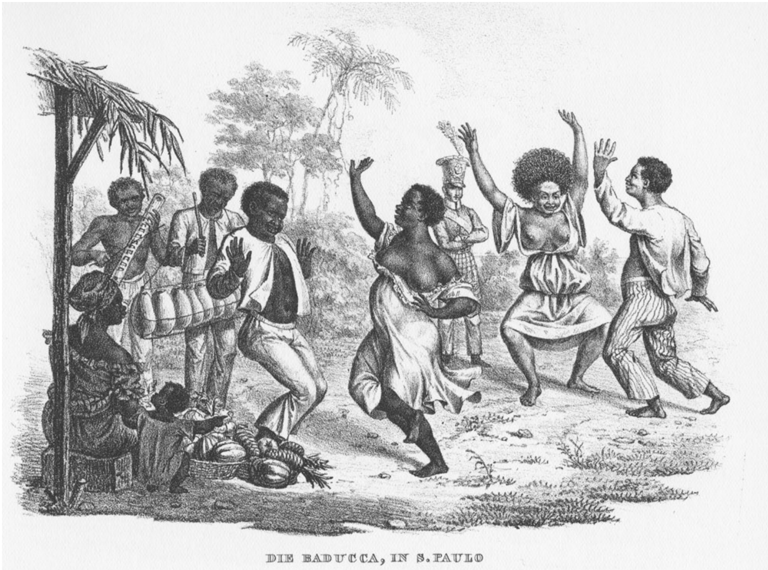

Figure 2.15: Dancers of *batucca* which may be the *batuque* or *lundu*, danced in São Paulo (published by Spix and Matius in 1823). Fryer (2000, p.99) argues that the dance is in fact *lundu*, due to the position of the arms.

Like in other reports, the the woman focuses on the movement of the hips and makes use the same pejorative terminology used in other reports from male observers. She offers a exotic description of an old man inducing the dance and a sexual display. However, the characteristics of this scene seem to indicate that she has witnessed a form of an African religious ritual where participants were induced to trance by the old men. It is comprehensible that this context would hardly be understood from the moral/cultural perspective of an European woman from the 1880s, but the reported perspective offers cues that help to reconstruct the original context of cultural clashes that gave rise to a hybrid Afro-Brazilian samba culture. The experience of “strange emphasis of the rhythms” could indicate the syncopated rhythm *tresilo* or other syncopated rhythm figure used by audiences to accompany dancers and musicians. The experience of this woman exemplifies how the cultural meaning of African religious practices could escape a non-acculturated subject.

2.5 Afro-Brazilian rituals

Influences of Afro-Brazilian rituals such as the *Candombé* and *Umbanda* religious systems always operated in the transformation of Afro-Brazilian music and dance and are still important for the samba context (Sodré, 1979; Carvalho, 2000; Browning, 1995; Mariani & Asante, 1998). Although there is no information about the connections of modern Afro-Brazilian rituals with ritualistic forms of *batuque*, it seems to be quite plausible that secular and ritualistic music were tightly connected to each other and perhaps overlapped each other in space, music repertoire and functions. *Candombé* and other Afro-Brazilian practices are based on oral tradition. They preserved a relatively orthodox structure for more than three centuries (e.g., great part of the vocabulary in the *Candombé* is still based on *Yorubá* and *Keto* languages) and are widely spread over a considerable part of the Brazilian territory. The same strategy that kept these practices alive through out centuries of slavery, captivity and prejudice may have retained some characteristics of the music and dance gestures until now. These characteristics may have been connected to all stages and socio-cultural groups that participated in the genealogy of samba. Why they are not often considered as components in the genealogy? Why is this element not included in the models of Chasteen (1996) and other scholars?

Two hypotheses were taken into consideration. Firstly, practitioners of African cults would not wish or permit that their practices were fixated in written documents. From this perspective, it seems obvious that the repression of and punishment for this sort of practice contributed to the obscurity of the influences of African traditions in the samba music until recently. Secondly, the texts of African culture exhibit different lexicons, semantics and primary mediations: fixation, memory or connection with religious deities are all realized through the body. African culture considers that dance is a part of music: myths are embodied in dances and even practitioners in the rituals offer their bodies to be "used" ("mounted" or possessed in trance) in the communication rituals with African deities. Since the notion of the body for a Western perspective was still pejorative in the 19th century, it seems natural that the text of African culture could only appear in documental sources when 19th's Western reports shed light on what was considered "vulgar" in Afro-Brazilian practices. This explains the constant focus on movements of hips of the mulatto women, even though the available iconography shows choreographies with large movements of the arms, hands and feet.

How could it be possible to build a documental and historical narrative based on dances and ephemeral bodies? How written documents produced in a 19th century colonial society could reflect a sacred body or a body empowered with tradition and knowledge? The embodied text of African culture remained unknown element to the Westerners until Western culture started to become mixed with the Pan-African culture (e.g., when the society started to consume the *black* dances or music from the diaspora in the 20th century) or until the sciences and theories of embodiment started to envisage that mind and body were not so divisible[13], during the 20th century.

[13] See Section 1.4.1

If we consider that this "invisible" axis of the Afro-Brazilian practices coexisted with the documented layer of narratives — *lundu*, *maxixe*, *batucadas*, *capoeira*, samba — we are able to formulate alternative hypotheses, which can be coherent with the apparent lack of parental links between styles, described in the last sections. In this alternative hypothesis, the connection of samba with the "African matter" is simply not established by a continuous sequence of styles (a parental three) but by the transit of dancers, musicians, participants between the ritualistic and secular spaces, between dances for worship and dances for entertainment, between dancing and making music and vice versa. In this respect, the documented styles could be seen as formulations of a Western viewpoint that were fixated in documents but remained rooted in poorly documented embodied practices of African and Afro-Brazilian culture. They can be simple projections of Afro-Brazilian practices onto the documental history or, if considering a different perspective, they can be viewed as reflections of the superficies of the Afro-Brazilian practices on the Western concept of music style.

Even though we do not focus on the history of Afro-Brazilian music and even though it is extremely difficult to offer proper proofs to support these hypotheses, we offer a propositive illustration of this model, displayed in Figure 2.16. In this figure, the vertical axis represents several tendencies that would affect Western and African viewpoints. The styles represented on the Western documental history reflect the Western viewpoint with regards to the African culture. Note that the time axis denote different systems of time: while in the Western culture the narratives are produced in a linear monochronic time, African cosmology tends to adopt a polychronic perspective (see Hall, 2000; Koetting, 2010, for more information about these two different time systems). This means a completely different dynamic of temporal, social and conceptual notions of practices in the structure of practices under African influence (therefore highly hypothetical) in contrast with traditional notions of evolution, change and record keeping of Western culture.

2.6 Early African and Western encounters

The cultural differences between Western and African cultures are reflected in the way individuals perceive sound and movement. From these first contacts between Africans that were forced to cope with European rules, and Europeans that never had contact with African musical priorities before, we are able to grasp some of the original Western perspectives on African practices. The following example, taken from a Belgian visitor visiting Brazil in 1870s, illustrates one of these views:

> "They take advantage of the slightest opportunity to give themselves up to dancing, their favourite amusement. It is interesting then to see them gathered in a ring under open sheds or on the asphalt of

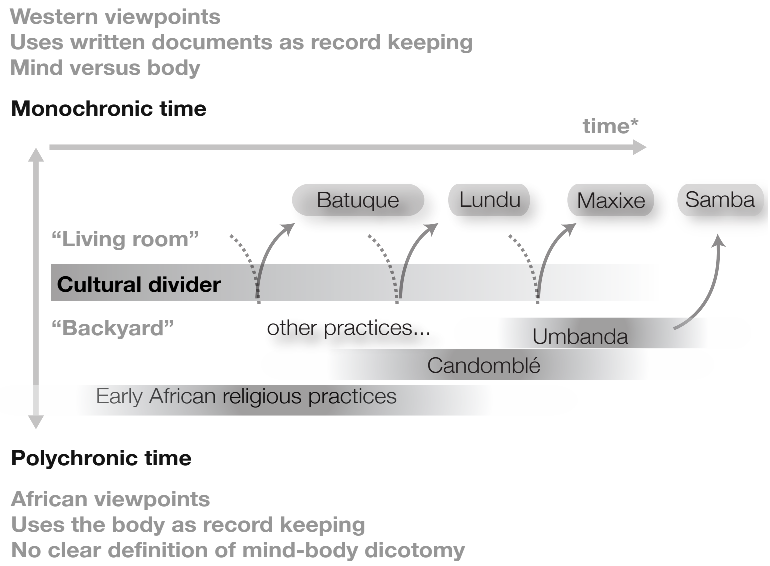

Figure 2.16: Propositive model/hypothesis on the genealogy of samba style in the documented Afro-Brazilian parental tree. The vertical axis represents several characteristics linked with the Western and African influences. The time axis (*) has different time systems for each pole — polychronic and monochronic — that are discussed in the text.

> drying-grounds, each in turn indulging in the most ludicrous leaps, doing so always to the same figure, to the sound only of drums made from skins stuck over hollow tree-trunks, with accompaniment from the lookers-on, who sing out of tune and clap their hands more or less in time."(Fryer, 2000, p.92)

As Fryer (2000) observed, "out of tune" means to him not according to the European concert scale, while "more or less in time" is probably an effect of the contrametricity of the rhythm of the hand clapping. Like in the report made by the French woman (described in page 46) the musical ambiguity works here as an barrier that keeps acculturated individuals engaged in the meaning formation behind the practices because they own tacit knowledge to tackle the information. At the same time, it alienates non-acculturated individuals from the meaningful elements of the practices. But how did these Africans or African decedents work out the ambiguous musical content? Is tacit knowledge sufficient to tackle the ambiguous information encoded in music?

When the visitor describes the gestures of the dances as being performed "always to the same figure" he may have inadvertently came across a key element necessary to tackle the system. The redundancy and periodicity of the gestures in the choreography could serve as a key for what was not understood in the rhythms. The role of repetitive movement in handling rhythmic ambiguity (as suggested in Sodré, 1979), participatory playing (as suggested in Chernoff, 1991) or tempo keeping (as suggested in Kubik, 1990) in Afro-Brazilian context is illustrated here in its most primitive form. The well-known complementarity of dance and music in African music (Chernoff, 1991; Stone, 1985) works here as a filter: dance disambiguates music, and those who are not participating will be alienated. Participants without the tacit knowledge of how movements are related to sonic patterns will listen, move and understand it differently.

2.7 Conclusion

In the last sections, we discussed how a group of problems raised in the confrontation between African and Western-European viewpoints to culture influenced the knowledge of music and dance forms in samba. We have observed a tendency to incorporate reports on dance-music relationships taken from a purely documental sources that obviously privileged a limited view on the context. The historical narratives left over from the available documental sources about African and Afro-Brazilian traditions reflect a Cartesian notion of body, dance and culture from the Western 18th and 19th century's society.

The consequence of this process is a mixture of information about music forms derived from dance forms and dance styles appearing in the context of music forms whose relations are not properly revealed. There appears to be plenty of formal and historical parallelisms between dance and music styles, which are not well discussed in relation to the dance gestures. Above all, there is a superficial or incongruent interpretation of embodied practices in Afro-Brazilian culture illustrated by narratives in which dance and music forms are separated and dance gestures are disregarded by only attaching sensual connotations to the movements[14]. This contributes to the underestimation of the importance of dance, oral and religious traditions in the Afro-Brazilian culture. In the next sections we will propose several methods and describe experimentes that aim at clarifying the structure and relationship between dance and music in the Afro-Brazilian samba.

[14] It does not mean that the samba dances are absent from sensuality but that they convey other meanings and even other culturally specific non-Westernized forms of sensuality.

3

A Cross-modal Heuristic for Periodic Pattern Analysis of Samba Music and Dance

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Abstract

Samba delimits a privileged cultural territory, which is populated by a diverse set of dance and musical expressions. Although several authors have stressed the fact that music and dance are intrinsically coupled in samba culture, there is a lack of proper methods that allow the description of this relationship in terms of musical patterns and body movement. In this study, we develop a method to unravel this relationship, using a computational heuristics that provides an analysis framework to find periodic patterns connected with meter in dance and music. The method is applied to a limited universe of samba dances and music, which is used to illustrate the usefulness of the approach. In particular, we show that an interesting coupling can be observed between dance and music at the metrical level. The results allow us to make the description of shared structures, such as synchronized patterns and spatial gestures, under the common framework of meter. Evidence for the enactment hypothesis is revealed by the contrast between binary tendencies in dance patterns and polymetric ambiguity in music. It is likely that the musical ambiguity of samba forms is a basis for the active engagement of dancers in re-enactment processes, thus providing a framework for embodied meaning-formation.

3.1 Introduction

In all human societies, dance and music appear as significant components of human expression (Hanna et al., 1979; Grau, 1983; Brown et al., 2006), representing symbols, rhythms, intentions, gender roles, coalitions, sense of space, affect and emotions. Dance and music practices induce very strong experiences of 'reality' and 'engagement', which contribute to the development of social bonding and cultural identity (McNeill, 1995). The Brazilian society embodies this phenomenon through dance and music forms of the samba culture (Mariani & Asante, 1998). Indeed, the samba delimits a privileged cultural territory, which is populated by well-known forms of dance and musical expressions, personal and social behaviours and symbolic manifestations of national identity. The culture of samba is undeniably linked with the traditional Carnival calendar, but even more so in a variety of subcultures in which samba dance and music are further developed, changed and maintained.

According to several studies in musicology, history and anthropology, samba represents the most recognizable Brazilian form of dancing, music making and social engagement (Browning, 1995; Chasteen, 1996; Mariani & Asante, 1998; Moura, 2004). However, the methodological basis of these studies rely on the analysis of texts, speeches, scores, and transcriptions of samba dance and music, and rarely examine complementary descriptions such as body movement, sound, resonance, interaction, muscular bonding and associated experiences (Desmond, 2000). Yet, the role of the human body in establishing the intrinsic relationships between music and dance, and social embodied interaction, could highly contribute to a better understanding of samba as a component of the Brazilian cultural dynamics, and similar traditions in other cultures. How can we understand this relationship between samba dance and samba music, and what methods can be used to unravel this relationship?

Though several authors have argued that an analysis of body movement should be taken into account as a concrete '*way of knowing*' (Desmond, 1994; Sklar, 1994), it is only recently that a proper methodological and theoretical framework has become available, which allows an empirical study of the intrinsic relationship between music and dance. This framework, called embodied music cognition, is inspired by enactive approaches (Varela et al., 1991), theories of entrainment (Clayton et al., 2004) and neurophysiological evidence of a tight coupling between perception and action in the so-called mirror-systems (Gallese, 2001; Rizzolatti & Craighero, 2004). Within the field of embodied music cognition, Leman (2007a) develops the viewpoint that the human body can be conceived as a natural mediator between experience and physical environment. Through body movement, experiences are acquired that motivate the participation in social interaction. In view of social communication, one could say that body movements provide corporeal articulations that reveal (or share) these experiences to (or with) other social agents. Dance provides an evident example of music-driven body movement with known effects on experience and social bonding. But how does it work? To what extent can we say that dance is a re-enactment of music, or that dance is the embodiment of music? To what extent can we go deep into the intrinsic relationship between music and dance?

The present study aims at developing a method that allows the study of the intrinsic relationship between music and dance from the viewpoint of embodied music cognition. We hereby focus on the characteristics of periodic movements, in particular on the intrinsic relationship between periodic patterns of music and dance. By using examples of samba dance and music, we show that interesting couplings can be observed between the two modalities at the metrical level. In this paper, we develop a method to unravel the nature of the periodically and metrically related patterns of dance and music, using a computational heuristics that provides us with a periodicity analysis framework, which can be used as a tool to penetrate into the shared structure between music and dance. The limited universe of samba dances and music on which this method has been applied, does not support the formulation of detailed conclusions for samba. Yet with this limited data-set it is possible to illustrate the usefulness of the approach and to lance a number of tentative hypotheses about samba dance and music.

The paper is structured as follows. In the first part we describe the actual knowledge about samba music and dance forms (Sections 3.2 and 3.3) and the necessity to develop a cross-modal analysis to approach coupled dance-music forms (Sections 3.4 and 3.5). In the second part we describe a cross-modal method for periodicity analysis of dance and music, illustrated by a series of dance excerpts (Sections 3.6 and 3.7). In the final part in Sections 3.8 and 3.9 we analyse the results and the performance of our method and discuss the preliminary observations and the perspectives of the cross-modal method, using a limited set of examples.

3.2 The structure of samba music

The constant interchanges between western contexts and non-Western roots that characterize the dynamic culture in which samba evolves (Chasteen, 1996; Sandroni, 2001) make it difficult to make fixed generalizations about samba forms or traditions. However, the history of samba music is often seen as an outcome of the lundu-maxixe-samba genealogy, which denotes not only a group of music styles but also related dance forms that influenced each other in an intricate cross-fertilization between styles and modalities. *Lundu* (first documented in 1780) is considered to be a 'fundamental link' between old African forms of batuque and samba (Fryer, 2000, p. 154), but this is poorly documented in the scientific literature. Anyhow, the *lundu* music was linked with the first national dance of the same name, which dominated Brazilian social dances until 1870 (Sandroni, 2001, p. 39). By the end of the 19th century, a new couple dance appeared, which could be accompanied not only with *lundu* music, but also with habanera or tango music. This resulted in the *maxixe* dance, which emerged not only as a couple dance but also as a new musical form or/and a new way of playing music (Chasteen, 1996; Fryer, 2000). The *maxixe* paved the way for the samba style that emerged in the suburbs of Rio de Janeiro at the beginning of the 20th century. Sandroni (2001) suggests that modern samba assumes its actual form in the 1930s, when the music was adapted to the walking steps and tempo needs of the Carnival parade.

Samba music is generally described as having a binary meter music form, with accentuation in the second beat, and a rhythmic texture that is characterized by syncopated rhythms (Salazar, 1991; Chasteen, 1996; Mariani & Asante, 1998; Sandroni, 2001). However, there are other sub-styles of samba, which are differentiated from each other by a large range of variation of musical structure, lyrics, geographical distribution, choreography, instrumentation and nomenclature (Fryer, 2000). The *samba-carioca*, *samba-de-roda*, *pagode*, *partido-alto*, *samba-canção*, and *samba-enredo* are all typical samba music forms, which are played and combined with the choreography that we focus on in this study: the *samba-no-pé* dance style. Figure 3.1[1] shows an example of typical pagode/partido-alto rhythmic patterns found in a samba ensemble, proposed by Moura (2004, p. 203).

Other less evident generalizations can be added to this general definition of samba music. Homogeneous rhythmic structures can be found in the high or low

[1] Short explanation of samba instruments (based on Béhague, 2009; Loureiro, 1991; Galinsky, 1996): *Surdo* — large doubled headed bass drum played with one mallet in one hand and damped with the other hand. *Tantã* — mid-low instrument resembling a conga and played with the hands. *Pandeiro*— standard tambourine. *Tamborim* textemdash small cylindrical drum percussed with a stick. *Cuíca* — A Brazilian friction drum of African origin having a wood stick attached to the centre of its membrane. It is played by rubbing the stick with a wet cloth or hand, which vibrates the membrane and produces a roaring sound. *Ganzá*— A type of Brazilian rattle, often resembling a two-headed chocalho, usually made of metal. *Reco-reco*— A scraper from Brazil made of notched bamboo and scraped with a stick (similar to the *güiro*).

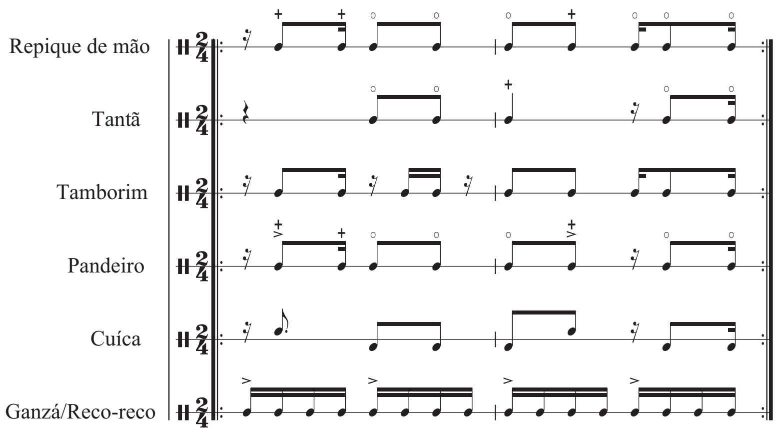

Figure 3.1: Rhythmic texture of the pagode sub-style proposed by Moura (2004). Surdo or tantã are examples of mid-low instruments that fill the low-frequency range in a samba instrumentation. Ganzá and reco-reco lines support high-pitched percussive lines. Other instruments such as cuíca sound in mid-high frequency textures.

extremities of the spectrum of samba ensemble. Bass percussions such as *surdo* and *tantã* tend to stress beat onsets, particularly at the second beat. The tatum layer — the lowest level of the metric musical hierarchy (Bilmes, 1993) — emerges from 1/4 beat onsets often performed by high-pitched instruments such as the *ganzá*, *reco-reco* or *pandeiro*.

Musicologists have often suggested a set of rhythmic formulas to characterize the rhythmic motives used in samba music, especially those performed by mid-range percussion instruments (e.g., *cuíca*, *tantã*, *tamborim*), melodic lines and soloists. Common formulas (or motives) are the *characteristic syncope*, *tresillo* and *cinquilho*, which can also be found in most of the African diasporas in the Americas (Sandroni, 2001). Other motives such as tamborim cycle (Araújo, 1992, quoted in Sandroni, 2001) or the Angola/Zaire sixteen-pulse standard pattern in Kubik (1979) are some examples of these rhythmical propositions. However, intricate poly-metric lines, ambiguous metrical cues, systematic syncopation, common improvisation practices and the constant evolution and proliferation of multiple forms of samba makes the task of proposing general rhythmic formulas for samba music rather difficult.

In a recent study using computer techniques in music analysis, Gouyon (2007) analysed the micro-timings of 16^{th} notes in samba polyphonic audio examples, revealing systematic deviaations in the 3^{rd} and 4^{th} onsets in each 4-group notes in the 16th-note level Lindsay & Nordquist (see also 2007, for a similar study). Wright & Berdahl (2006) studied micro-timings of pandeiro rhythms in samba music trying to describe the ‘swing’ structures by means of machine learning. Former studies have also approached samba music from the viewpoint of music information retrieval. Gouyon et al. (2004) was able to recognize 53% of samba songs from a database of 1360 songs (various styles), and Dixon et al. (2004) developed a method to classify genres with up to 99% of recognition based on the characterization of rhythmic patterns and other features. These studies, however, define samba as a quaternary form, whereas most musicologists would define samba as a binary meter music form. Moreover, although the musical context of swing or ballroom dances is commonly related with dance or spontaneous movements, none of the studies offered choreographic descriptions.

3.3 Samba dance

Similar to samba music, samba dance is characterized by a large variability of styles. Text-based descriptions often rely on an observation of body movement sequences, but such attempts are reported to be problematic in dealing with the profusion of simultaneous body relationships over time (Hanna et al., 1979; Ungvary et al., 1992; Desmond, 1994; Calvert et al., 2005). Browning (1995) provides an analysis of samba dance culture based on her immersive experiences in Afro-Brazilian dances. She describes dance as one of the ‘texts’ of Afro-Brazilian cultural resistance, providing textual movement descriptions of rituals, dancers’ movements and samba dances. Chasteen (1996) and Fryer (2000) use narrative descriptions of movement in their analysis of the social and historical development of samba. However, studies of samba dance that draw specific attention to the analysis of body movement are rare. Descriptions often focus on disassembled gestures, which are attached to specific symbols or facts but hardly provide a clue to understand the deployment of body movement in relation to music in time.

In one of the most detailed studies on samba dance Mariani (1986) used the Laban effort theory to describe samba choreographies. Interestingly, this study provides exhaustive textual descriptions of the movements of samba dances in time, accompanied by stick figures of the human body (Mariani, 1986, p. 335). Andrade (1991) also used such figures to describe the choreography of the *samba paulista* (a sub-style of samba that has evolved in São Paulo state). Blom & Kvifte (1986, p. 503) used the same visual representation to explain the functional relations between periodicity in Norwegian folk fiddle dance and gait movements. In short, the description of the articulation between body parts or between music and dance by means of text (without the support of figures) is not without problems.

There are a lot more studies about samba music than studies about samba dances. A number of these music studies provide factual references of choreographical elements (for example, people clapping or dancing along to music), however, without detailed discussion of the choreographicalmusical relationships. Indeed, it is not trivial to analyse the physicality of the body in space, neither to find elements to interpret the information from the body as a symbolic system. In addition, the role of the body in the development of musical forms can be easily masked by its ubiquity as exclusive mediator of human experience with the musical matter (what Desmond, 1994, referred to as ‘nearly unnoticed symbolic system’, p. 36).

3.4 The samba dance and music connection

Although some studies tend to separate samba music from samba dance phenomena, several authors emphasize their tight interconnection and interdependency. For example, Kubik (1990), in a study of polymetric rhythms of the *Batuque of Benedito Caxias* (Brazil), claims that the best way to detect common beat patterns along the percussion ensemble was to “look at the steps and general movement behaviour of dancers” (Kubik, 1990, p. 138). In a similar way, Sandroni (2001) stresses the relevance of walking steps in samba parades that incited the transformations that resulted in modern samba in the 1930s. The necessity to consider music and dance as a holistic phenomenon in samba culture was already discussed by Sodré (1979) in the late 1970s, and more recently by Browning (1995). Both authors noticed the effect of syncopated rhythms in producing movement reactions in the listeners, this is what Browning (1995, p. 9) called the ‘hunger’ for movement. Other authors, such as Fryer (2000), Pinto (2001) and Carvalho (2000), stress that the performatic unit of samba culture is inherited from Afro-Brazilian rituals. Such religious traditions ourished within inter-textual contexts, in which the “playing of instruments, dance movements, formalized costumes, kinetic displays, dramatization, etc., all these aesthetic expressions put together create an environment which passes the idea of continuity” (Carvalho, 1999, p. 10).

The analysis of the intricate relationship between samba music and dance is hindered by a lack of tools that allows the investigation at levels that extend beyond the phenomenology of visual and auditory observation. The necessity to find novel methodologies that solve the interdependence between music and dance in multimodal phenomena has been stressed by a number of authors. Blom & Kvifte (1986) analyzed dance and music performances of *Gangar* music suggesting that the intrinsic metrical ambiguity could only be solved by the analysis of the dancer’s movements or by the performance of traditional musicians playing together with dancers. Using examples of Norwegian Springar dance, Kvifte (2007) criticized the idea of imposing meter definitions using isochronous time marks. Analogous to Kubik (1990), Kvifte claimed that dance movements are key to define meter units. In African music contexts, which form the most important background of samba culture, several studies provided a number of similar observations about

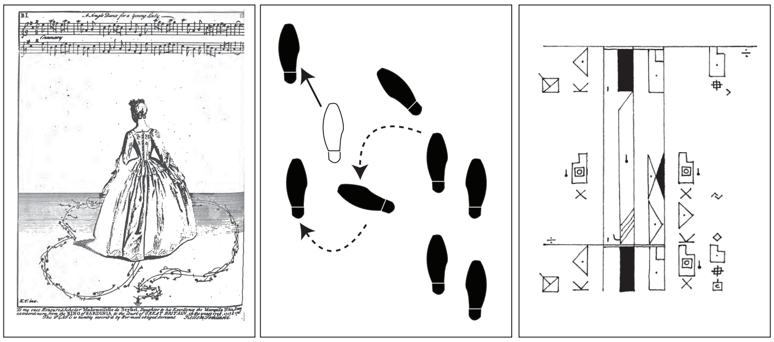

Figure 3.2: Evolution of dance notation: (a) instructional material from Art of Dancing Explained by Reading and Figures (Tomlinson, 1735); (b) 'Indecipherable maps of footprints' (Browning, 1995, p. xxi) often used to describe ballroom dances and (c) choreographical excerpt in Laban notation (Herbison-Evans, 1988, p. 46) by the International Society for the Arts, Sciences and Technology (ISTAT), published by MIT Press Journals, reproduced with permission).

the coupling of music and dance. Chernoff (1991, p. 1101) claimed, "when the [African] music relinquishes its relation to movement, it abandons its participatory potential".

3.5 Temporal and spatial descriptions of dance

In the past, descriptions of dance had been available as procedural codes, using sequenced text indications, images and videos. Figure 3.2(a) shows an instructional material from the 18th century, with descriptions of dance movements and a musical score (Tomlinson, 1735). Several dance notation systems such as Banesh, Stepanov, Conté and Nikolais notation systems followed a similar symbolic notation (see Guest, 1989). Banesh notation and Laban notation (conjugated with Laban analysis based on effort theory) had a great impact on the description of dance movement and seem to represent the strongest tendencies in dance notation from the second half of the 20th century to now. Nuntius (Ungvary et al., 1992), Emote (Chi et al., 2000), LabanWriter, Dance-Forms, and MacBenesh (see comparison in Ebeweuter, 2005) are examples of symbolic dance notation systems available in software packages.

Apart from symbolic notations, attempts have been undertaken to develop an empirical approach to music-driven body movement. For example, in studying conducting gestures, Becking (1928) drew pictures of the movement of the hand as a basic gesture of the meter. The goal was to examine the similarity of conducting movements between composers and styles (Nettheim & Becking, 1996). Alexander

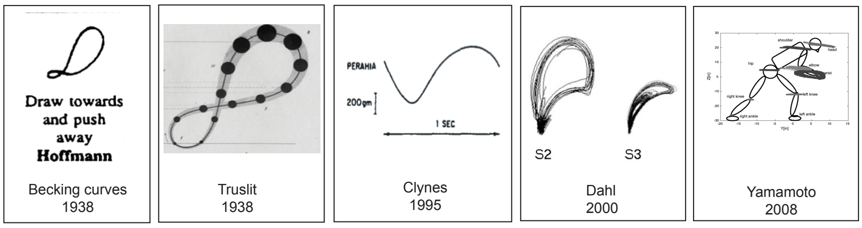

Figure 3.3: Evolution of gesture descriptions from Becking Curves to Yamamoto's motion analysis patterns. See explanation in the text. Sources: Becking (1928); Truslit (1938), Plate 1 (example pages); Reprinted from Clynes (1995, p. 273) with permission from Elsevier Science B.V.; Dahl (2000, p.227); Reprinted from Yamamoto & Fujinami (2008, p. 815), with permission from Elsevier B.V.

Truslit suggested that musical descriptors such as time, timbre and dynamics of music could be attached to elements of the drawing (Repp, 1993a). Clynes (1995) analysed finger movement of subjects exposed to different excerpts of classical music and proposed that each composers' pulse has a different 'trace'. More recently, Dahl (2000) analysed the motion trajectories of the arm of drum players using a motion capture system based on infrared markers. She observed that drummers use largely different movement strategies to play drum accents. Similar figures, which illustrate how people walk in response to music, were developed by Styns et al. (2007). More recently, Yamamoto & Fujinami (2008) used trajectory plots to describe movements of samba musicians. Figure 3.3 shows how these analyses of movement in music contexts have developed from subjective observation and drawing in Becking and Truslit diagrams, to more objective approaches using kinematic measurements, such as the description of playing technique in Dahl and Yamamoto's patterns.

In the 1980s, Camurri and colleagues developed a platform for dance and music analysis (Camurri et al., 1986, 2000). The platform, called EyesWeb, is based on the extraction of low and mid level features, such as trajectories of dancers in space, quantity of motion and contraction index (Camurri et al., 2003, 2004). Inspired by this approach, Jensenius (2006) developed a visualization technique called Motiongrams to study gesture in free dance movements. Shiratori et al. (2003, 2004) used a cross-modal method that segments dance movements with information extracted from musical rhythm in Japanese traditional dances. Guedes (2006) developed tools to extract musically relevant rhythm from dance in real time, using spectral features. Enke et al. (2006) used accelerometers to translate 'inherent' rhythm of dances in music and found problems concerning ambiguities in the process of rhythmic motion derivation. Matsumura et al. (2006) studied skill acquisition in samba dance, analysing dancers' movements with accelerometers attached on the back of the lumbar. They observed correlations between accents in music and accents in dance.

What we propose in the next sections is the development of a new method for the empirical study of the relationship between music and dance. The method is based on video analysis and descriptions that resemble Becking curves. It will be illustrated by means of original samba music and dance excerpts. Given the samba context, our approach focuses on music and dance choreographies in which repetitive patterns occur. We hereby focus on the development of a cross-modal method that allows the description of dance through the lenses of the music metrical properties. More particularly, we describe dance using a temporal (metrical) framework that addresses both the musical (sonic) domain, as well as the dance (body movement) domain. The metrical coupling of music/dance is examined in a computational heuristics that provides us with a periodicity analysis framework, which the researcher can use as a tool to penetrate into the shared structure between music and dance.

3.6 Method

3.6.1 The periodicity transform

The description of periodic patterns, in both movement and sound, is a key factor in the analysis of music and dance. So far, methods such as Fourier analysis (e.g., FFT), wavelet transforms, filter bank decomposition and autocorrelation analysis have been used to examine periodicity in music-related signals (Lidy et al., 2007; Mandel & Ellis, 2007; Tzanetakis, 2007). However, the application of these methods to human movement (and in some cases, also musical rhythm) is not without problems.

Take for example an FFT analysis. Since motion capture systems based on video have limited and often low temporal resolution (e.g., 30 frames per second in video) it may be difficult to distinguish between different shades of the body's (own) eigen-frequency (at about 2 Hz) (MacDougall & Moore, 2005; Styns et al., 2007). One may be inclined to increase the FFT window, but this is at the cost of losing the fine temporal resolution and, consequently, detection of sudden movements. The sinusoidal and orthogonal basis of the FFT is furthermore unsuited to deal with human movement, since the latter tends to lack orthogonality and hardly be conceived as a sum of sinusoidal movement shapes. Indeed, variations of the deployment of repetitive movements are more perceptible than the variations of its periods. A dancer can perform a completely different dance in the same period. Likewise, a dance can be performed during quite different periods, retaining the same movement deployment. Autocorrelation and cross-correlation methods may avoid some of the problems related with temporal resolution but they lack the spatial descriptions of the movement deployment of a found period (i.e. the periodic pattern).

The Periodicity Transform (PT) copes with the limitations mentioned above in that it searches for periodic events in the data, decomposes signals onto its proper basic periodic patterns (called its bases), and locates periods of these periodic patterns and respective measures of energy (norm) in relation with the signal. The PT was introduced by Sethares & Staley (1999) and further applied in rhythm analysis (Sethares & Staley, 2001), analysis of brain waves (Lo & Leu, 2005), video and audio integration (Ravulapalli & Sarkar, 2006), data mining (Cai et al., 2007) and bioinformatics (Brodzik, 2007).

Figure 3.4 compares Fourier analysis, autocorrelation method and Periodicity Transforms in their ability to retrieve the energy and period representation of periodicities of a given movement signal. The top graph displays the original movement signal (first graph). Although the resolution in this example is sufficient (30 samples per second) to describe the frequency range of dance movements, the FFT analysis (second graph) lacks the description of the basis (lack of waveform) and low frequencies (large periods) show poor resolution. The autocorrelation analysis (third graph) has a finer resolution at low frequencies but it also lacks the description of the periodic patterns. The last graph demonstrates the energy measure resulting from the PT 'projection' of all sampled periods (autocorrelation and PT analysis have the same resolution for the signal). In all of the above, the phase relationships with the music signal are absent in these representations.

The main idea behind the PT is to decompose the signal onto periodic sequences by projecting a given list p of periodic patterns onto a 'periodic subspace' P. The mathematics of the 'projection' procedure is based on a modified form of the *Projection theorem* from Luenberger (1969), as described in Sethares & Staley (1999, 2956).

Interestingly, the results of the decomposition depend not only on the projection onto periodic subspaces, but primarily on a predefined heuristic that manipulates the list p. For example, the algorithm *small2large*, proposed by Sethares, builds an initial list composed of periods that range from the smallest to the largest one in the sequence (Sethares suggests to limit the range from 1 sample to 1 of the signal sample length). The iteration is followed by subtracting each pattern P_n with a particular period from the signal x, and then using the residual signal $r = x - x_p$ to find the next periodic pattern, which is again subtracted from this residue signal, and so on. Using this heuristics, the PT will provide an output composed of (i) periods of each periodic pattern, (ii) the energy that each periodicity extracts from the original signal, and (iii) the set of periodic patterns (in fact, a set of basic waveforms) that provide an analysis of the signal (see Sethares & Staley, 1999). The measure of energy extracted from the original signal by the periodicity is

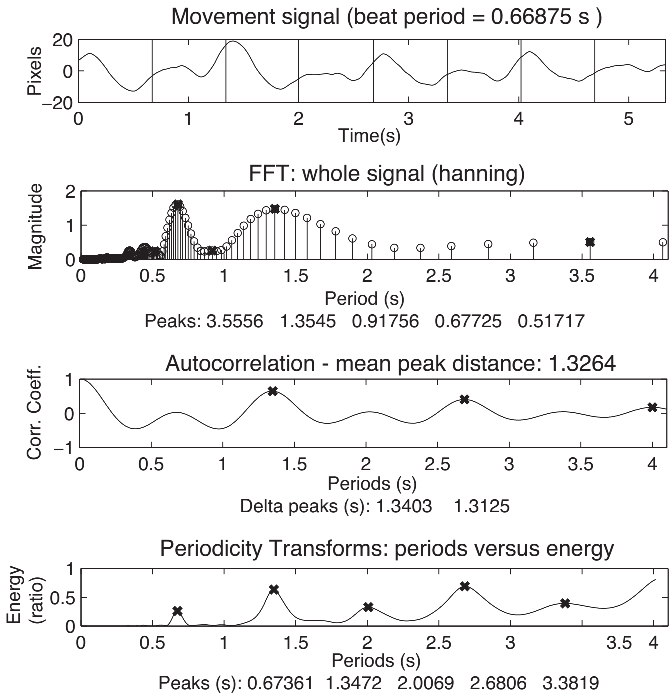

Figure 3.4: FFT analysis (zero-padded, whole window analysis using Hanning smoothing window), autocorrelation and energy measure retrieved by PT projections of a dance movement signal with a period of repetition around 1.35 s (two times the beat period of the music).

calculated as the norm or the inner product of the periodic pattern with the signal (Sethares & Staley, 1999, p. 2954).

Unlike other methods such as Fourier or Wavelet transforms, the PT finds its own bases, which, moreover, are non-orthogonal. The latter implies that different heuristics (that is, different orders of projections and subtractions from the signal) lead to different results. Like autocorrelation, PT offers a better resolution at low frequencies than Fourier analysis, because it is linear in the period (see Figure 3.5). The PT approach further allows the extraction of both the temporal aspect (duration of the period) and the spatial aspect (the deployment of the periodic pattern between two period points). Figure 3.5 illustrates the PT decomposition of a vertical movement of the right hand of a samba dancer (shown at the bottom of the figure). The two graphs on top show periodic bases, found in the so-called *Best-Correlation* heuristics of Sethares. The dotted lines indicate the length of the basic periodic pattern that will be repeated in time until the end of the length of the signal. The

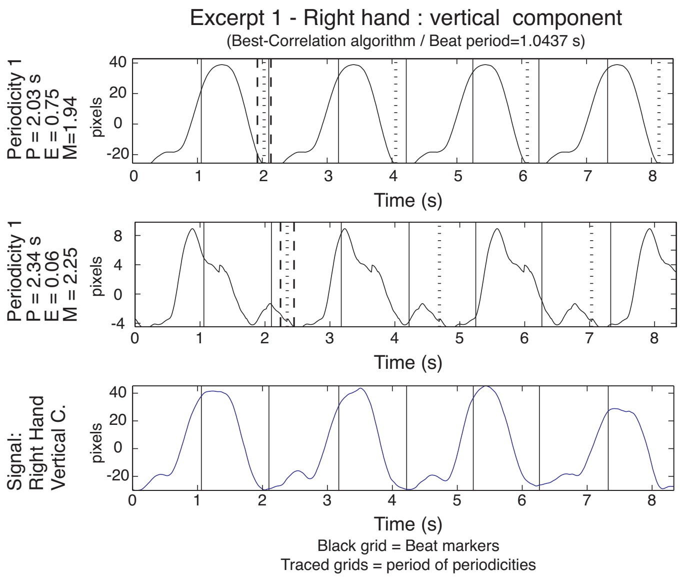

Figure 3.5: Periodicity in movements of the right hand, using Sethares' Best-Correlation heuristics. The first periodicity (top graph) seems to correlate with the metrical layer of 2 beats ($M = 1.94$). The second periodicity does not synchronize with any of the metrical layers ($M = 2.25$), and is rather insignificant in terms of energy ($E = 0.06$).

first dotted line is surrounded by dashed lines that indicate a tolerance region for slight variations in the beat. The labels on the left indicate the period in seconds (P) and the so-called energy (E) of each periodic pattern. The label (M) indicates the ratio between the period of the periodicity and original beat period, which will be used to identify it if the periodicity is coherent with a metrical layer.

Sethares & Staley (1999) proposed four heuristics, namely, B*est-Frequency*, *Best-Correlation*, *M-Best*, and *Small-to-Large*. These heuristics differ in how to select, order and limit, and iterate the set of periodic patterns. However, in view of our aims, these heuristics are not fully adapted to a cross-modal analysis of samba dance and music:

- The *Best Frequency* heuristics derives the list p from the peak components of a DFT (discrete Fourier transform) analysis of the signal. Then, the algorithm iterates following a descendent order of strong DFT components. However, the resolution of the DFT at low frequencies is not sufficient for dance movements and non-metrical periods may be overestimated.

- The *Small2Large* heuristics performs a scan of periods ranging from the smallest one (1 sample length) to a given limit and iterates. Such strategy results in poor results because the periodic dance movements with small periods are privileged, which has no reasonable connection with the priorities of dance.

- The *Best-Correlation* heuristics compares each period projection with the original signal, trying to find the best correlated periodicities in relation to the signal. This approach gives good results when the periodic movements do not interfere with other non-choreographical movements. However, important hidden periodicities can be sub-estimated if the original signal has random events. Periodicity of dance does not emerge uniquely from the movement itself, but in engagement with music. Correlation with the signal seems to be an incomplete parameter to evaluate a period of dance movements.

- The *M-Best heuristics* maintains a list of the most powerful periodicities. When a new (sub) periodicity removes more power from the signal than one currently on the list, the new one replaces the old. Such a procedure gives good results but the heuristics limited by internal features of the signal may underestimate metrical movements related to music (external to the signal). We assume that the performance of the heuristics could be improved if the elements of the list p (periods to be projected), or any further manipulation of it, reflect the nature of dance. Accordingly, we propose a new cross-modal heuristics, which extracts a list of periodic patterns from body movement using metrical properties of the music.

3.6.2 A cross-modal heuristics for periodicity transforms

What is the main rationale for choosing one or another heuristics for periodicity transforms? In general, one could argue that a heuristics for finding period patterns should be based on domain knowledge. In our domain of application, dance movements are driven by music, and consequently, it can be assumed that there is a music-dependent force that somehow constrains the dancer's movement. Domain knowledge will therefore be determined by biomechanical constraints of the human body, and by the cultural constraints that relate to music and dance.

There are good reasons to assume that the period of the beat (also expressed as BMP, number of beats per minute) and its organization into meter and larger-scale dance rules is a determining factor in the embodiment of music. The beat indeed reflects the eigen-frequency of the human body in response to music (MacDougall & Moore, 2005; Styns et al., 2007; van Noorden & Moelants, 2007), and therefore, it can be considered to be a fundamental drive for movements (Thaut, 2005). In the present approach, we take the beat as the most basic period to which the human body synchronizes its movement in music-driven dance. In addition, we also take into account the metrical system that is associated with the beat, that is, we take into account the periods that correspond to the multiples and divisions of the beat period. This metric system is assumed to be a proper structure for embodiment in samba dance. The justification of this hypothesis is linked with the viewpoint that music-driven dance relies on the embodiment of perceived musical structures, through corporeal articulations (Leman, 2007b). In dance, these corporeal articulations are organized along learned movement patterns. Evidence for the embodiment mechanism is based on a mirror-system, that is, a tight coupling of perception and action due to shared neuronal regions in the human brain (Gallese, 2001, p. 606).

Consequently, an appropriate heuristics for a samba dance analysis can be based on two basic rules, namely, (i) that relevant dance movements are consequences or inductors of musical metrical layers (they may reflect these layers and provide synchronized or counterpoint movements in relation to musical sound), and (ii), that large movements will be more relevant than small movements.

These rules correspond to the domain knowledge on samba, namely, that samba dance and music are rhythmically and metrically organized (Sparshott, 1995; Mariani & Asante, 1998) and that observers tend to perceive large body motions more clearly or/and dancers tend to put more effort into acting out large movements (the latter is linked up with the human preference for the perception of biologically relevant movements). For an overview about this topic, see Tversky (2003).

The heuristics is cross-modal in the sense that it looks at dance through the lenses of the musical meter. We thus use knowledge from one domain to look at a second domain. However, the heuristics can also be applied to the musical domain, using information about the meter. In that way, music and dance can be analysed with and represented by basically the same tool.

3.6.3 Implementation of the heuristic's algorithm

Based on the former assumptions, we developed two heuristics, called respectively the *Best-Route* and the *Any-Route* algorithms, using knowledge about musical meter. Both heuristics build a preliminary list of the energy (norm) for the projection of each period, on which peak values above a threshold th are detected. These peak values represent the most relevant periodicities, which are selected by its proximity with the periods of the metrical layers in music ($p \in ml$). This process is demonstrated in Figure 3.6.

The difference between the two heuristics resides in the processing of the lists of metrical peaks pm (see Algorithms 1 and 2). The *Best-Route* heuristics process this list removing the periodic pattern from the original signal, leaving the residual $r = x - x_p$ stripped from its p -periodic patterns for subsequent iteration. In contrast, the *Any-Route* heuristics skips this step by projecting all periodic patterns $p \in ml$ onto the periodic subspace P_p directly from the signal

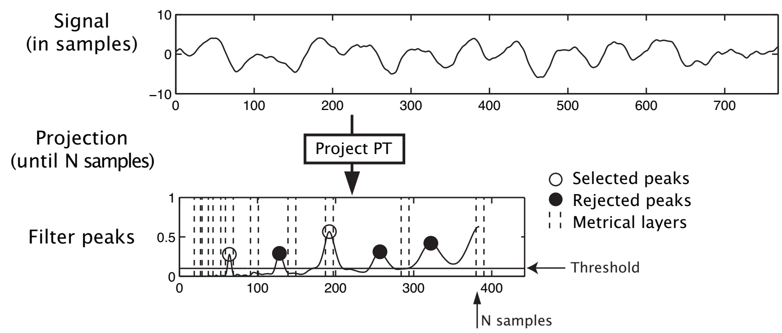

Figure 3.6: Each sampled period of the signal (until N) is projected using PT. The peaks of the energy profile (in the sense of the norm measure) are then filtered by its proximity with metrical layers. This list of 'metrical peaks' (pm) is maintained in both heuristics.

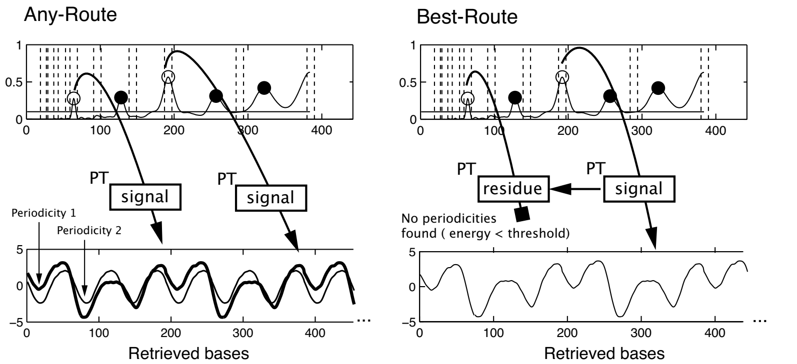

Figure 3.7: Sequence of processing of metrical periods for both *Any-Route* and *Best-Route* heuristics.

(while $p \in ml$ is more powerful than a threshold th). In other words, the *Best-Route* heuristics tackles metrical ambiguity by privileging powerful periodicities that match the structure of the musical meter. The *Any-Route* heuristics looks for a set of powerful (but ambiguous) periodicities that are likely to be evident due to its metrical relevance but it does not reject the metrical ambiguity. These two heuristics are shown in Figure 3.7. In this example, the *Any-Route* heuristics retrieved two metrical periodicities, which are rather similar. In the *Best-Route* implementation, the second projection over the residue from the first one did not result in any relevant periodicities (the first periodicity absorbed most of the energy, leaving little room for the projection of the second periodicity).

Algorithm 1 Pseudo code of the *Any-Route* heuristics

For signal x, $N =$ number of samples of x, $ml =$ metric grid, $th \in (0, 1)$ and $P =$ periods to be projected

for $p = 1, 2, 3, ..., N/2$ **do**
    Project $x_p = \pi(x, p)$ (PT projection, Sethares & Staley, 1999)
    $pm_p = ||x_p||$ (Norm of the signal)
end for
Select a decendent list of pm into pp
Filter periods in pp that are close to any value of ml
for $pf =$ filtered periods of pp **do**
    Project $x_p = \pi(x, P_{pf})$
    if $||x_{pf}|| > th$ **then**
        Store x_{pf} (basis), $||x_{pf}||$ (norm) and pf (period)
    end if
end for

The differences between *Any-Route* and *Best-Route* heuristics are important because they offer different ways to interpret the periodicities of the signal. Which one of the heuristics should be preferred depends on the goal of the analysis. If the analysis aims at describing the diversity and relative magnitude of metrical structures in dance movement or sound, the *Any-Route* heuristic is likely to outperform the *Best-Route* heuristics. The reason for this is that it hypothesizes a series of non-chained periodicities, that is, it accepts that other factors rather than only meter and magnitude could inuence the engagement in one periodicity. However, if the analysis aims at finding the best hypothesis to explain the periodicity of the metrical engagement, and if explanations are determined by meter coherence and magnitude of the periodicities, then the *Best-Route* heuristics will be considered the best choice.

The use of a metrical grid, or metrical layers, to select the best periodic periods in the *Any-Route* and *Best-Route* heuristics is based on a priori knowledge of the metric structure (either in the music or in the dance). Once the BPM is known, we assemble the metrical grid with a collection of factors of the beat (1 beat length):

$$ml = [0.25, 0, 33, 0, 5; 0, 66; 1, 1.5, 2, 3, 4] * \textit{beat period}:$$

When multiplied by the beat period, these factors include periods of macro and micro structures of the meter. In samba, a bar is 2 beats length. Multiples of the bar (4 beats length) and polymetric lines (e.g., 3 beats) may also be expected. Micro metrical structures such as the tatum layer (0.25 beat factor) are considered as well. Ternary structures can also be represented by the factors 0.33, 0.66, 1.5 and 3.

The pseudo code of these heuristics is described in the Algorithm 1 and Algorithm 2.

Algorithm 2 Pseudo code of the *Best-Route* heuristics. (*) indicates the differences between the *Any-Route* and *Best-Route* heuristics.

For signal x, $N =$ number of samples of x, $ml =$ metric grid, $th \in (0, 1)$ and $P =$ periods to be projected

for $p = 1, 2, 3, ..., N/2$ **do**
    Project $x_p = \pi(x, p)$ (PT projection, Sethares & Staley, 1999)
    $pm_p = ||x_p||$ (Norm of the signal)
end for
Select a decendent list of pm into pp
Filter periods in pp that are close to any value of ml
$r \leftarrow x$ (*)
for $pf =$ filtered periods of pp **do**
    Project $x_{pf} = \pi(r, P_{pf})$
    if $||x_{pf}|| > th$ **then**
        $r = x - x_{pf}$ (*)
        Store x_{pf} (basis), $||x_{pf}||$ (norm) and pf (period)
    end if
end for

In the next sections we show how the above cross-modal heuristics for periodic pattern analysis can be applied to samba dance performances.

3.7 Analysis and synthesis of periodic patterns in samba dance

The aim of this section is to illustrate the application of the cross-modal heuristics for periodic pattern analysis to samba music and dance. The analysis of dance starts with analysing video recordings and the tracking of pixel-positions of body parts (Section 3.7.1). The movement data is then decomposed into two dimensions, namely, the vertical and horizontal pixel positions. Each dimension is then analysed, and recomposed in its original two-dimensional (video plane) aspect (Section 3.7.2). The analysis provides a set of representations of periodic patterns that describe samba dance movement in space and time. The analysis of music starts with a decomposition of the auditory stream into perception-based filter banks, from which we extract the metrical constituents.

3.7.1 Dataset and movement tracking

3.7.1.1 Data collection

Two professional Brazilian dance teachers (male and female) performed six dance sessions, using samba music from their own repertoire. The instructions for the

Table 3.1 Description of the songs selected by the dancers to perform the dances.
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Excerpts	Title	Composer	BPM	Record
1 and 4	Espelho	João Nogueira	57.5	João Nogueira and Paulo Cesar Pinheiro - Parceria - 1994
2 and 5	Ela veio do lado de lá	Benito Di Paula	76.3	Brasil Som 75 - Benito Di Paula -1975
3 and 6	Do jeito que a vida quer	Benito Di Paula	89.21	Benito Di Paula - Benito Di Paula - 1976

dance performance were (i) to dance in samba-no-pé style (see Section 3.3), (ii) to perform homogeneous and simple dance steps, (iii) and to organize the dance in a frontal presentation. In this study we only concentrate on homogeneous excerpts with a length of 8 musical beats.

The samba music was chosen by the dancers themselves, in a tentative manner to create a natural context based on the familiarity with music and dance elements. They were asked to agree upon three samba pieces, from less to more 'danceable'. Each dancer danced to the three samba pieces (excerpts 1 to 3 from male and excerpts 4 to 6 from female), which brings us to a total of six dance performances. The songs were composed and performed by popular samba composers. Table 3.1 shows the samba pieces and their tempo (expressed in BPM), from which the beat period can be derived. The first column refers to the dance excerpts.

The conditions of the dance recordings hardly reflect the natural dance context, but we expect that professional experience of the dancers may somehow compensate for the ecological infringement. Indeed, samba dance professionals may have developed a better 'body image' of the dance form than novices, and display a deeper awareness of differences regarding other dance forms. We therefore assume that their way of performing is more concentrated in the objective tasks that aim to demonstrate samba dance forms.

3.7.1.2 Tracking movements

In this study, 9 body points were identified and marked, namely, nose, left shoulder, left hip, hands (left and right), knees (left and right) and feet (left and right). The trajectories of these body points were determined by using manual movement tracking. This technique, although time consuming, has been used in ethnographical studies and in speech analysis with considerable results (Clayton et al., 2004; Rossini, 2004). It consists in marking and recording the position (horizontal/vertical

Figure 3.8: Frame-by-frame manual tracking. Each white dot represents one position marked with the mouse using visual identification (for illustrative purposes the size of the points shown here is bigger than the original). The original EyesWeb-patch offers a visually recognizable mark definition of 1x1 pixel along a special definition of DV-NTSC format (720 x 480 pixels).

pixel position) of a desired visual element for each video frame (see Figure 3.8).

The video recordings were realized using a 3CCD Mini-DV camera and professional microphones, registered in DV-NTSC format at 30 fps and audio resolution at 48,000 samples per second. The manual annotation, as shown in Figure 3.8, was carried out using a specific patch in EyesWeb (Camurri et al., 2000). The analysis resulted in a set of 18 vectors (2 x 9 body parts) for each dance excerpt, using the same temporal and spatial definitions of the video format (30 frames per second of temporal resolution and 720 by 480 pixels of spatial resolution for the entire image).

We then segmented the vectors in such a way that they corresponded to 8 musical beats (4 bars). This was done in order to have a precise representation of the dancer's behaviour along 4 bars. The beat markers and mean beat periods used to calculate metric layers from the music were extracted using a manual inspection of beat tracking with the software Beatroot (Dixon, 2007).

The signal corresponding to these patterns was then resampled to 768 samples in order to have a proper factorable integer as the total sample. As described in Sethares & Staley (1999, p. 2961) this procedure optimizes the performance of the algorithm by improving the detection of the expected periodic patterns, in this case, patterns that correspond to the periods of the metric layers. A low pass filter was also applied to the signal in order to eliminate deviations from the manual annotation. The signal was also subtracted by its mean in order to avoid the inuence of the DC offset (resulting from the pixel position) while calculating periodicities (for easy recognition of indications by the reader, right and left sides will be referenced here from the viewpoint of the observer — inverted in relation to the viewpoint of the dancer).

3.7.2 Periodic patterns, Becking curves, and dance gestures

A dance movement can be simple and overtly repetitive along one spatial dimension. However, dance movements are frequently more complex, sometimes not periodic and improvisational, sometimes periodic but ambiguous. A movement can show strong binary periodicities in the lateral displacement. At the same time it can show contrasting ternary periodicities in the vertical direction. It can also be perceptually ambiguous if, for example, short period repetitions are grouped and give the impression of bigger periodic sequences. In that type of movement, the best periodic pattern cannot be directly defined. The final interpretation becomes an active disambiguation process in which other factors than movement periodicity may interfere.

Our approach provides some alternatives to offer such a context in dance and music. For dance movements that are strongly coupled with the metric levels of music, the *Best-Route* heuristics tends to offer the simplest explanation. Strong coupling results in a situation where the heuristics is able to find a very powerful periodic pattern in the metrical grid that 'explains' a great part of the dynamic of the signal. Most of the energy will be subtracted by this period, which will leave little room for other decompositions that apply over the residue.

However, if the signal is ambiguous but metric, that is, based on polymetric periodicities, then residues tend to leave room for subsequently but significantly less powerful decompositions. In certain cases, and especially where the signal dynamics of one metric level overlap and consequently mask the other possible dynamics of another level (e.g., multiples like 2 and 4), it may be better to apply the *Any-Route* heuristics if such masking is undesirable. If movements are intrinsically not metrical, or metrical in other very contrasting tempi, both heuristics will ignore such periodicities because the selection of peaks will block non-metrical elements (see Figure 3.7).

3.7.2.1 Exploring spatial periodicities

By applying the *Best-Route* and *Any-Route* heuristics to the movement vectors, we obtained (i) the periods, (ii) a measure of energy, and (iii) bases of the most powerful patterns whose periodicities synchronize with the metrical grid. Figure 3.9 shows an example of the analysis of the horizontal displacement of the left hand (excerpt 1, male dancer, musical beat period $= 1.04$ s), using the *Best-Route* algorithm. The periods (P) of the two most powerful periodicities correlate with 2 ($M = 1.99$) and 3 ($M = 2.92$) times the beat period ($P = 4.16$ s and $P = 3.12$ s, respectively) and extract a ratio of $E = 0.58$ and $E = 0.04$ of the energy of the signal, respectively. In a similar way, Figure 3.10 shows an example of the complementary vertical displacement of the left hand in excerpt 1. The two most powerful periodic patterns showed the presence of periods very close to those of the metrical layers with 3 and

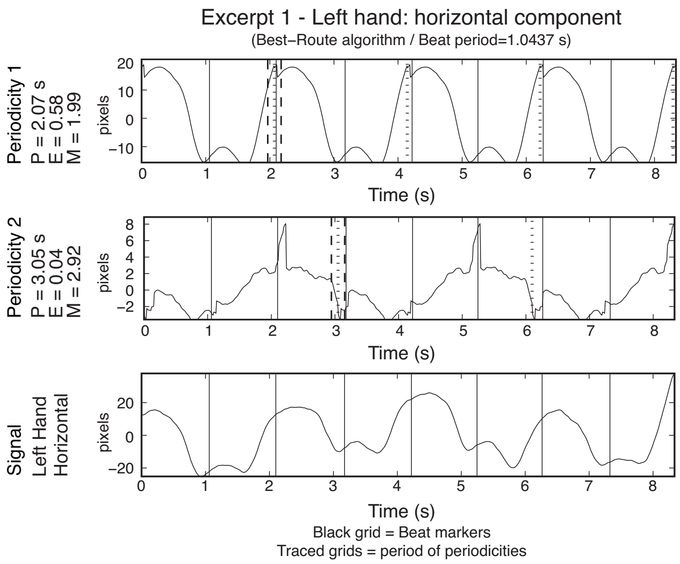


Figure 3.9: Analysis of the horizontal movement pattern of the left hand (excerpt 1, male dancer, musical beat period $P = 1.04$ s).

4-beat length ($P = 2.08$ s and $P = 3.12$ s, respectively). They extract a ratio of $E = 0.78$ and $E = 0.03$ of the energy of the signal, respectively.

In the case of the *Best-Route* algorithm, the energy of the above-mentioned periodicities can be summed up to a total that represents the part of the energy of the signal that is contained in metrical periodicities (for Figure 3.9, $E = 0.62$ and for the Figure 3.10, $E = 0.81$), because it decomposes the signal from subsequent operations into the signal and residues. Likewise, the ratio of residual energy (which in this case is 1 subtracted by 0.62, $E = 0.38$, and 1 subtracted by 0.81, $E = 0.19$) can be interpreted as the part of the signal that is (i) not engaged in the metric structure defined a priori, and/or simply (ii) not periodic. In the case of the *Any-Route* algorithm, the absolute sum or mean value of energy measure is not meaningful because the periodicities are not subsequent decompositions of the signal. However, the proportions of energies between metrical layers can lead to good indications of the 'metrical profile' of the universe (e.g., dances or body parts). As mentioned above, mean values of energy of the periodicities along dances or metrical levels must be interpreted with care, respecting the particularities of each method.

A visual inspection over the signal and the most powerful periodicity ($E = 0.58$) displayed in Figure 3.9 shows that the periodicity pattern with a length of 2 beats is able to explain the overall behaviour of the signal.

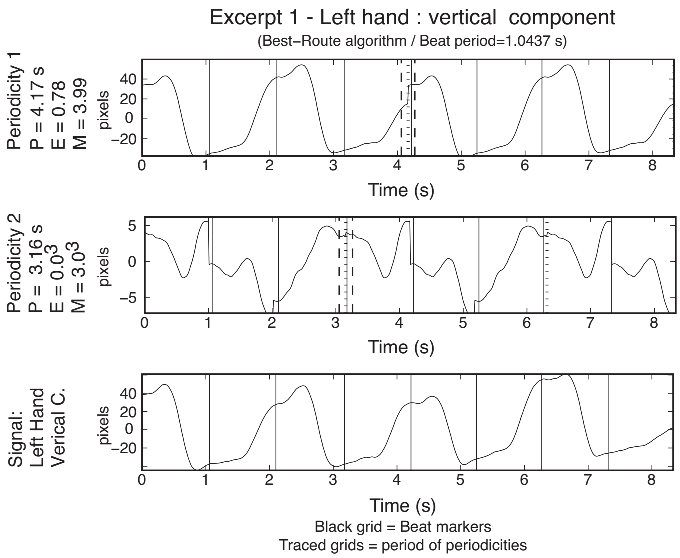


Figure 3.10: Analysis of the vertical movement pattern of the left hand (excerpt 1, male dancer, musical beat period $P = 1.04$ s).

Unfortunately, periodicities displayed in one dimension deliver incomplete information, because they are based on a reduction of the two-dimensional planar perspective of the video. At first sight, one could conjugate the periodic patterns from each dimension. However, there is no guarantee that the analysis in both dimensions leads to periodic patterns in the same metrical layer. This problem is illustrated by the analysis displayed in Figure 3.9 and 3.10 (horizontal and vertical component of the left hand). The most powerful periodic pattern in the horizontal dimension has a length of 2 beats (Figure 3.9, top panel), while the most powerful periodic pattern in the vertical dimension has a length of 4 beats (Figure 3.10, top panel).

We solved this problem by 'forcing' the PT projection onto its complementary dimension. Thus, if there is only one evident periodicity for a given metric layer in one dimension, then we project its period onto its complementary dimension. In other words, we use domain knowledge (namely the period duration) from the first dimension to find the periodic pattern in the second dimension by projecting the periodicity directly onto it. Two complementary periodicities are able to reconstruct a general spatial view that represents the periodic shape of the movement in video. In addition, the original time domain evolution of both vectors can be maintained by placing markers showing the evolution of the pattern along subdivisions of the metric level.

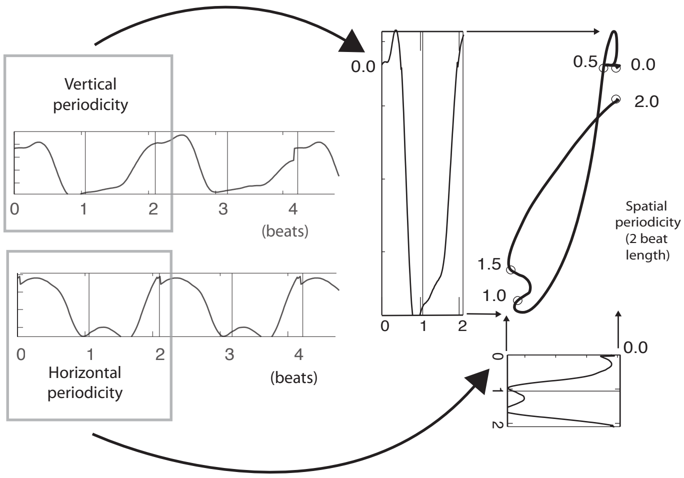


Figure 3.11: Reconstruction of the pattern of the left hand (male dancer, excerpt 1), in the metrical level of 2 beats (Bar).

Figure 3.11 illustrates the process of reconstructing the two-dimensional movement, starting from periodic patterns in the vertical and horizontal dimensions. The small circles on the two-dimensional periodic pattern indicate 0.5 beat steps in its temporal deployment. The resulting pattern is similar to the Becking curves shown in Figure 3.3. Reconstruction of the pattern of the left hand (male dancer, excerpt 1), in the metrical level of 2 beats (Bar).

This method allows us to represent the repetitive movements in the expected metrical levels as 'gestures', that is, as entities of body movement that can be conceptualized as body images, and perhaps further decomposed into smaller units of elementary gesture patterns (see also Li & Leman, 2007).

The non-orthogonality of the set of periodic patterns implies that the gestures — here conceived as a two-dimensional reconstruction based on the periodic patterns from the vertical and horizontal vectors — are dependent on each other. This property leads to two ways to interpret the results.

On the one hand, using the *Best-Route* heuristics, the periodicities are the results of defined choices and are successively stripped out of the signal. In this case, the most powerful periodicities may have taken over some part of the other periodicities and left behind low levels of ambiguity. The gestures resulting from this computation may be interpreted as being the best 'hypotheses' for the periodic movement, if it is considered that important periods are the large movements that fit between the boundaries of the metrical layers. However, a listener or witness is not perceptually passive (Leman, 2007b), and one can redirect perceptual effort to other possible periodicities, not necessarily large ones. In such cases where a set of possible choices is taken into account, the use of the *Any-Route* heuristics would be more appropriate.

In the *Any-Route* heuristics, the set of periodicities are always derived directly from the original signal, without computation of residue. The gestures that resulted from these *Any-Route* periodicities should be conceived as an overview of metrical 'possibilities', hypothesis or patterns that are likely to be individually perceived although intrinsically ambiguous. For that reason, the use of the *Any-Route* heuristics is the most appropriate for giving general overviews of the metric structure.

3.7.2.2 Exploring gesture comparisons

Figure 3.12 shows a gesture grid composed of 'Becking' curves of the left hand of the male and female dancer during the six excerpts (horizontal axis), and in all metrical layers (vertical axis).

The differences and similarities observed along all metric layers (columns) provide us with interesting information about the dancing gestures. The Becking curves display the hypothesized movement contribution as seen in each metrical layer, although not all metric layers may be perceptually evident. Note the differences between the two dancers. The male dancer (Excerpts 1 to 3) tends to move the left hand in a vertical position, while the female dancer (Excerpts 4 to 6) tends to move the left hand in a horizontal position.

Although such curves resemble trajectory descriptions or mean paths of trajectories, our method lies in a more sophisticated heuristics that searches for periodic patterns along the signal. It provides not only a general basis of repetition that allows us to rebuild the trajectories in a periodic representation, but also a systematic connection with periods and relative energy measures of these movements. It surpasses frequency definitions of Fourier methods in low frequencies and shows insightful representations in terms of basis. It represents a different alternative for multivariate visualization techniques (e.g., recurrence plots) because its results are similar to visual trajectories in video or any other visual media and analogous to perceived movement profiles. The Becking curves in the metrical level 2.00 seen in Figure 3.12, for example, represents how left hand movements are repeated on the video screen at every two beats, during the entire dance excerpts.

Finally, in order to have a global picture of the periodicities and distribution of these energies along the body we developed a global representation of our data, similar to the representation of periodicities from Flannick et al. (2005). This graph (see Figure 3.13) shows a visualization of the mean energy of periodicities found in each part of the dancer's body. The mean energy of the group of periodicities is

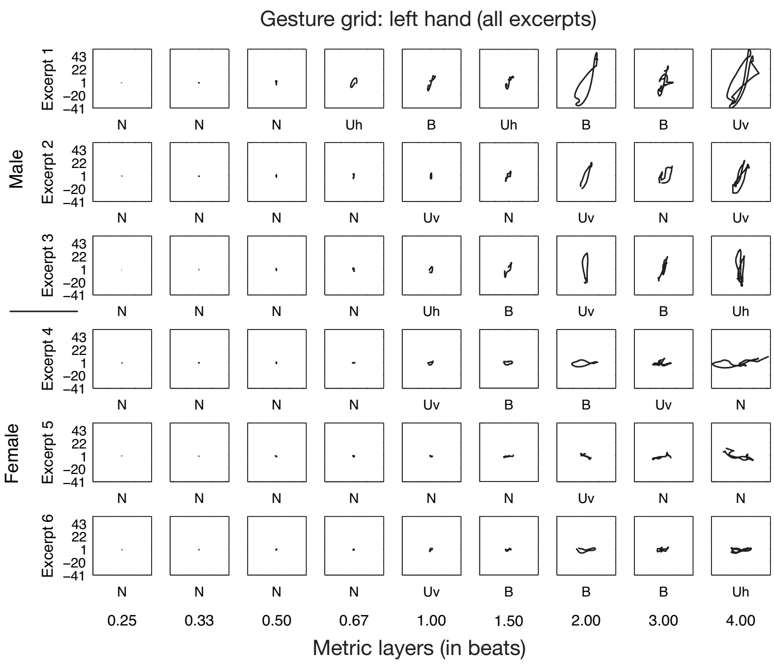


Figure 3.12: Becking curves of samba dances. Left hand gestures of the male and female dancer in all excerpts (horizontal axis), in all metrical levels (vertical axis). Each box represents a gesture according to the Becking curve (with vertical and horizontal dimension of the movement).

normalized and displayed as degrees of grey and placed on its period 'slot' or bin (the actual definition of these slots is 1/40 of the beat).

By using this set of methods we aim to describe the samba dance form in terms of basic gestures (rooted in repetitive metric patterns) and use these descriptions to study how repetition in dance movements show the deployment of bodily engagement. The method can be extended to other dance forms in which movement repetition is important.

The next section explains our approach to analyse extended to other dance forms in which movement meter in music using the same framework of the analysis of the body.

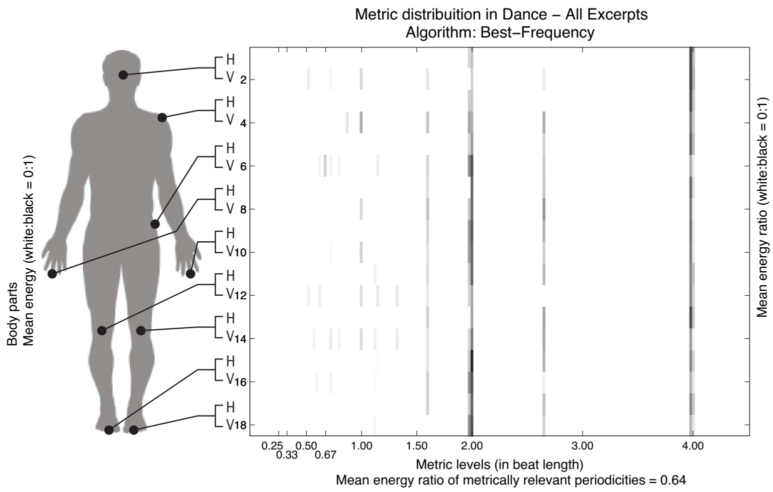


Figure 3.13: Image of the periodicities from each body part. Mean energy ratio of periodicities is normalized to degrees of grey(0:1 = white:black). Black pixels represent strong periodicities.

3.7.3 Applying the heuristics for periodic pattern analysis on samba music

We applied the heuristics for periodic pattern analysis on audio analysis, using an auditory model described in detail in Van Immerseel & Martens (1992)[2]. This auditory model implementation simulates auditory decomposition in the periphery of the auditory system (see the diagram on the left of Figure 3.14), which results in loudness vectors of 40 channels obtained from neural rate activity (Van Immerseel & Martens, 1992, p. 3514). On these 40 channels we applied the heuristics for periodic pattern analysis, using the very same approach as described for the periodicity image of body movement. Figure 3.14 (left panel) shows the results. For each channel we calculate the mean energy (norm) of the periodicities for each metrical level. The results were normalized to represent the ranges of energy as degrees of grey colour (0-1). The *Any-Route* heuristics finds all possible metrical hypotheses and their relative weight in the auditory channels. Keep in mind that the metrical grid is the same used to calculate metric periods for dance and music analysis.

[2]See also the IPEM toolbox available at http://www.ipem.ugent.be

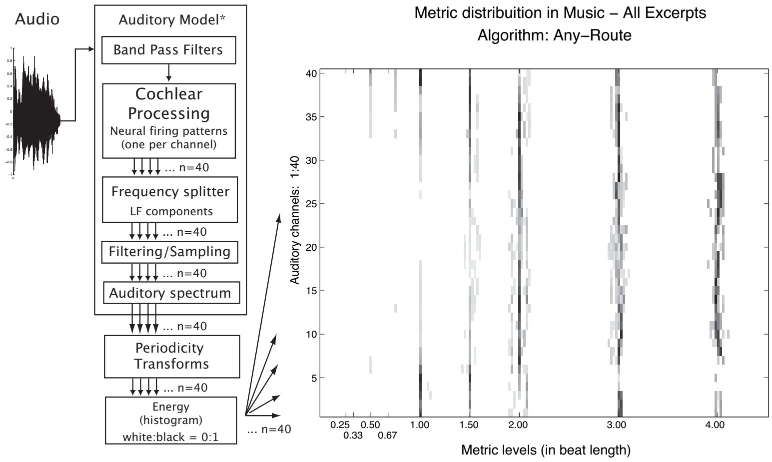


Figure 3.14: Diagram the computational process involved in the generation of the periodicity auditory images described in the text. Mean energy ratio of periodicities is normalized to degrees of grey(0:1 = white:black). Black pixels represent strong periodicities.

3.8 Analysis results and discussion

In this section, we apply the above method to a limited set of samba music and dance excerpts. In Section 3.8.1, we offer a general description for the embodiment of meter over different excerpts. In the Section 3.8.2 we explore the spatial descriptions of gesture grids (described in the Section 3.7.2) looking for differences and similarities that emerge from group comparison among dancers, stimuli, metric layer and magnitude.

3.8.1 Metre in music and dance

3.8.1.1 Overall results

An overview of the meter-related periods in music and dance was obtained by applying the *Any-Route* heuristics to the audio and movements of all dance excerpts. Figure 3.15(a) shows the mean, standard deviations and variance of their energy (norm) that is associated with the periods of the audio stimuli; Figure 3.15(b) displays the same analysis over movement of the dancers. Interestingly, the music results (a) show the expected polymetric characteristic of samba music, with a prominent 4-beat layer mixed with ambiguous ternary and binary levels. The dance patterns (b) have their energy level mainly concentrated within 2-beat periodicities,

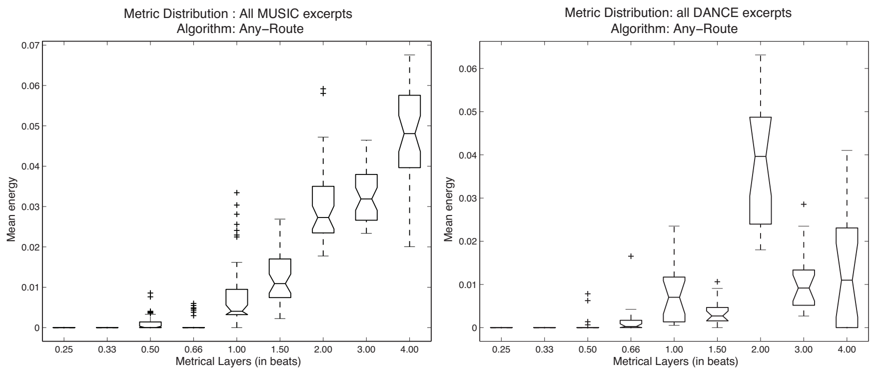


Figure 3.15: (a) Metric distribution (mean of power norm extracted by each periodicity) over music excerpts. (b)Metric distribution over dance excerpts.

and this energy is significantly higher than in other metrical layers. In other words, the presence of binary metric tendencies in the dance is more prominent than in the music.

The following analyses of distributions of metric energy display the distribution of the periodicity energy in more detail.

Metre distribution in audio Starting with the audio analysis, Figures 3.16 and 3.17 display a detailed image of distributions along the 40 channels of the auditory spectrum. The first result in Figure 3.16 is based on a heuristic that was extensively used by Sethares and colleagues (Sethares & Staley, 1999, 2001; Sethares, 2007) to approach meter in music (audio). This approach is based in the Best-Frequency heuristics, which is based on a DFT analysis of the signal. Figure 3.17 shows a similar representation, using the *Any-Route* heuristics and applying it to audio. This is based on a search for strong periods in the metrical grid. These two examples demonstrate the difference of results obtained with both implementations.

The horizontal axis represents metric layers while the vertical axis represents the 40 auditory channels from the auditory model. Black pixels represents high periodic energy. Vertical shadows on the image thus suggests a tendency of concentration of energy in a metric layer over the auditory channel span. The mean of all periodicity in a metric level was normalized between 0 and 1 (respectively white and black values). In the following figures, for example, it is clear that this power is very prominent in layer 2, 4, while less prominent in layer 1 and 1.5.

Metric distribution in dance movement The same visualization can be obtained by applying the same processes over movement. In the first figure (Figure 3.18)

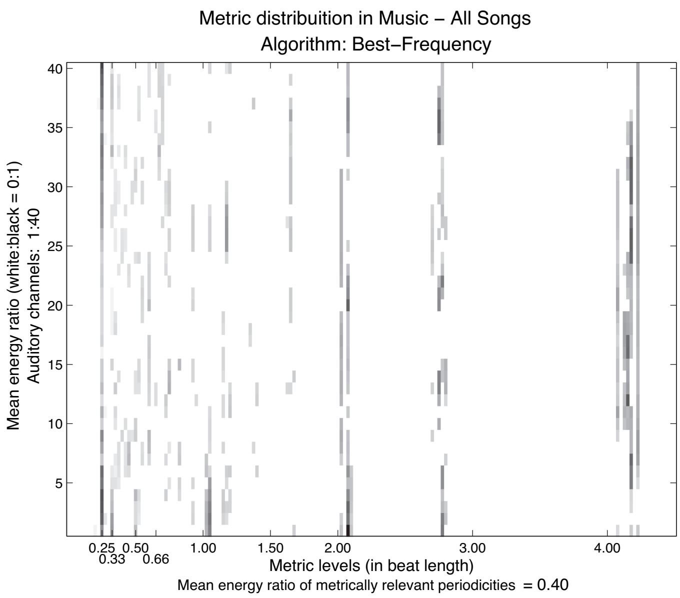


Figure 3.16: Image of the distribution of energy in each auditory channel (mean energy ration extracted by each periodicity) using the Best-Frequency algorithm. The same procedure was used in Sethares' publications.

we show the analysis using Sethares' Best-Frequency heuristics. In Figure 3.19 the analysis of movements is computed using our *Any-Route* heuristics. These visualizations were explained in detail in Section 3.7.3.

3.8.1.2 Discussion

The results of Figure 3.15 reveal that relevant observations can be obtained by studying how samba dance and music interact with each other. While the metric energy in the auditory spectrum is not clearly concentrated in one metrical level, the energy in dance movements is quite prominent in the 2-beat metric layers. Results from audio analysis are supported by the literature discussed before, which describes samba music as a polymetric form. However, the binary meter of samba music, which is strongly recognized within musicology, is much more evident in the results of metrical content of dance than in the apparent ambiguous meter of the auditory stream. This seems to suggest that perception of body movements that stress particular repeating strucsamba may be movement-based in the sense that through tural cues so that they become important within the self-movement (of the dancer in response to music) experience of the temporal organization of the music. musical patterns get rhythmically disambiguated. The The mere act

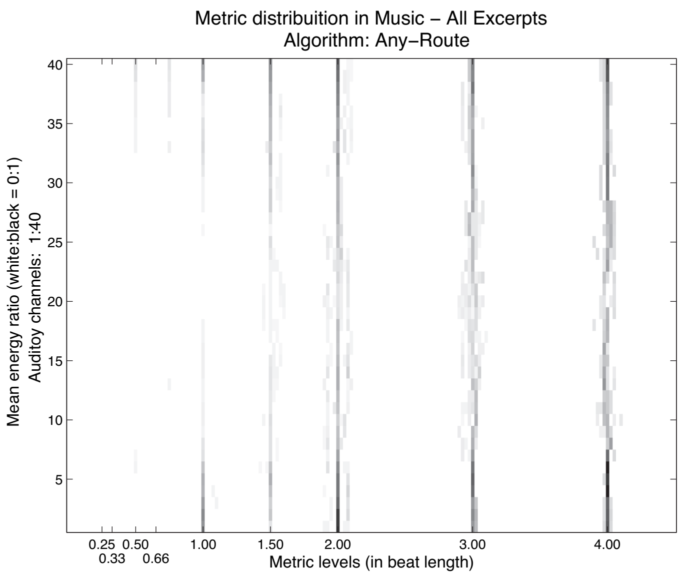


Figure 3.17: Image of the distribution of energy in each auditory channel (mean energy ration extracted by each periodicity) using the *Any-Route* algorithm. The *Any-Route* implementation shows here an overview of emergent metric energy encoded in repetitive patterns in all samba excerpts.

of disambiguation can thereby be seen as a perceived musical structure should be seen as the result of meaning formation act, because it allows the body to resonate with (or filter) a preferred metric structure that is slightly hidden in the music. The process requires an active contribution from the listener. The phenomenon may be related to the work of Phillips-Silver and Trainor (2005), who trained human infants to do this by bouncing them to every second versus every third beat of an ambiguous auditory rhythm pattern. They proved that this training inuences whether that auditory rhythm pattern is heard in duple form (a march) or in triple form (a waltz). Because infants did not engage in self-movement, it was concluded that the observed effect likely involves the use of vestibular and perhaps proprioceptive systems. A similar effect was obtained with human adults who jumped up and down by bending their knees (Phillips-Silver and Trainor, 2007)

However, if we look at the distribution of periodicities along the auditory stream (Figure 3.15), other interesting features can be observed. While periodicities in low frequency channels show a harmonic and structured metric disposition, stressing the beat, measure (2 beats) and the double measure (4 beats), it also leaves some room for polymetric patterns, reinforcing the 3-beat layer. Mid-range auditory spectra

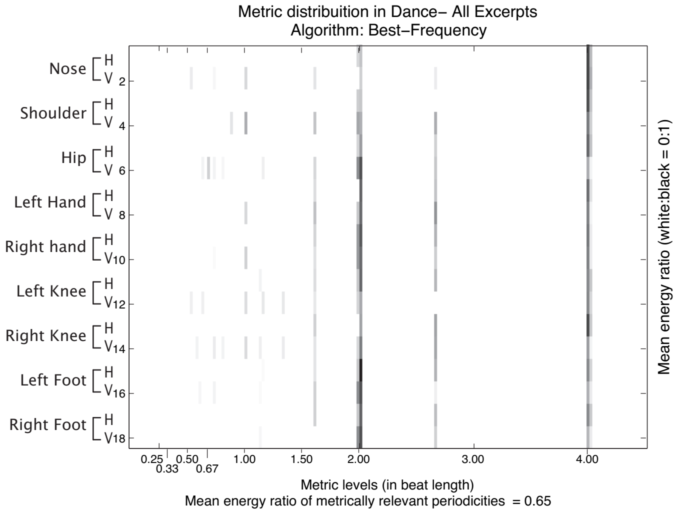


Figure 3.18: Image of the distribution of metric distribution in each of the 9 body parts using the Best-Frequency algorithm (mean energy norm extracted by each periodicity).

exhibit diverse poly-metric periodicities, probably related with syncopated formulas performed by mid-range instruments. Fast structures provide the tatum dynamics with 1/3 or 1/4 beat fast onsets, probably accentuated in polymetric repetitions with 1, 1.5, 3 beat lengths. Such polymetric structure, which is based in the accentuation of fast onsets, is able to challenge and reinforce the metric line sustained by the low instruments. We applied an onset detection algorithm (based on auditory module from the IPEMToolbox, Leman et al., 2001) to song 2. Figure 3.20 shows the result of this analysis, which illustrates the occurrence of the structure mentioned above in a representation of attack events along time.

The distribution of metrical energy along the audio channels, as displayed in images in Figure 3.16 and 3.17, indicates the presence of a 'column' of 2-beat periodicities. This distribution of 2-beat periodicities spread over all channels of the auditory stream may be a factor that justifies the perception of the binary meter, although the absolute energy values are less powerful than other metrical levels.

The Best-Frequency algorithm recognizes the 3-beat level as a beat level at about 2.7. This deviation is probably due to the resolution of the DFT. The poor resolution of the DFT at low frequencies combined with the intrinsic lack of orthogonality of the method implies that better explanations of the periodicity of the signal may be covered by approximated results.

The presence of 4-beat periodicities is also strong in our audio analysis. It is known that non-acculturated subjects often tend to interpret samba music as a

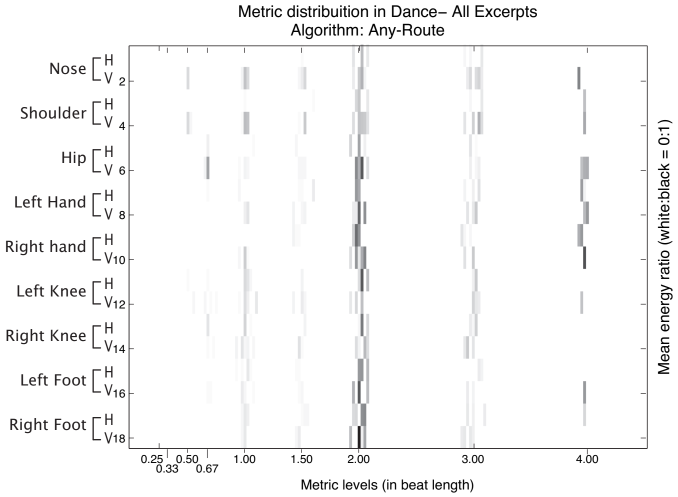


Figure 3.19: Image of the distribution of metric distribution in each of the 9 body parts using *Any-Route* algorithm (mean energy norm extracted by each periodicity).

quaternary form, which can be justified in part by its harmonic ambiguity derived from the binary form but also by the information extracted from the auditory stream. It is also possible that the metric layer 4 (4 beat other shorter periodicities. The tendency to have higher length) reflects an artifact imposed by the process of PT energy at longer periods is inherent to the algorithm calculations, because larger periodicities may contain because bigger repetitions are likely to extract more energy from the signal, due to the fact that constant periodicities tend to be grouped by its bigger repetitions (Sethares, 2007, p. 138). A possible solution would be to constrain the length of the periods according to the eigen-frequencies found in beat perception (Van Noorden & Moelants, 1999).

3.8.2 Overview of dance gestures

3.8.2.1 Results

An overview of metrical variance between dances performed by the female and male dancer is shown in Figure 3.21. There is no significant metrical difference between the two dancers. In both cases, the texture of metric movements seems to be larger and more powerfully concentrated in binary forms, compared to the metrical structures in music (see Figure 3.15).

When metrical gestures are grouped in a grid, spatial differences or differences

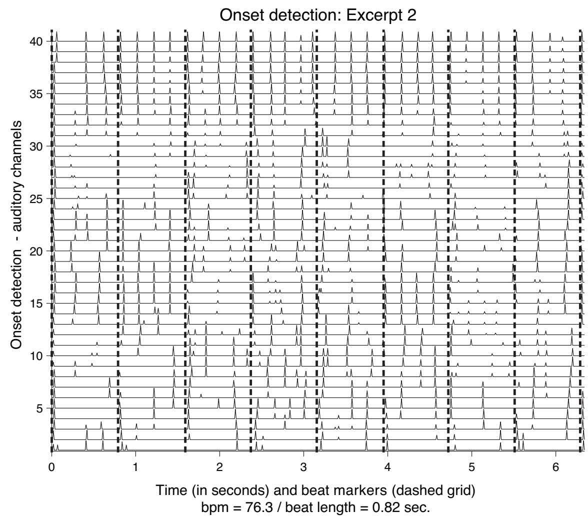


Figure 3.20: Onset detection image based on the auditory model images.

related with the contours of repetitive gestures become evident, as exemplified by Figure 3.12 (left hand) and the following Figure 3.22 (right hand); right and left positions are in relation to the observer (not relative to the dancer).

Note that in both Figure 3.12 and Figure 3.22, the male dancer tends to perform more diagonal shapes, while the female tends to move more horizontally, waving the hand below the torso, in a pendulum-like movement. It was also observed that dances danced in slow tempo show larger movements, suggesting that fast tempo is characterized by not only fast movements, but more straight lines in choreographical space, or less curved gestures.

Another interesting difference found in these excerpts is related with the gesture trajectories of the feet. The movement of the feet has a strong importance in samba dances and in other Afro-American dances. The feet develop not only choreographical functions but its trajectories may guide the ow of weight of the body and anticipate postures. Figure 3.23 shows a grid of patterns performed by the right feet in all dances. Note that the effect of the perspective, caused by the higher position of the camera, contaminates the vertical component with a third dimension related with deepness.

An analysis of the distribution of the periodicities across the stimuli is displayed in Figure 3.24 (songs 1, 2 and 3). There is a tendency in metrical levels 2 and 4 to suggest that the tempo might inuence the metric distributions of dancers' movements. Although not statistically significant, they seem to display more quaternary dance periodicities when the music has slow tempi and more binary

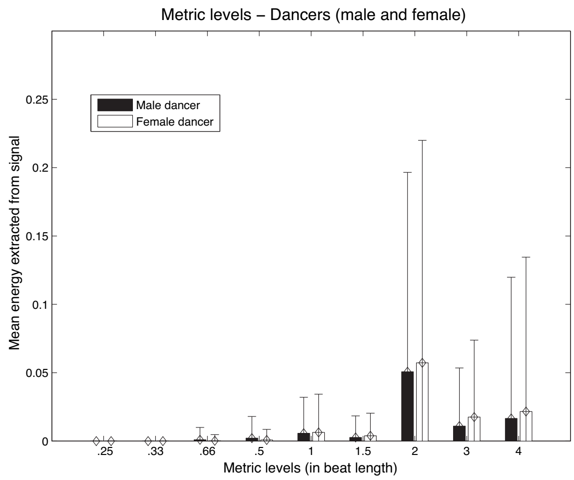


Figure 3.21: Mean energy and standard deviation of periodicities found across all body parts in all excerpts.

dance forms when music has fast tempi (song 3).

3.8.2.2 Discussion

The analysis of tempo in the music excerpts chosen by the dancers for this experiment resulted in increasing BPM levels (57.5, 73.3 and 89.21 BPM), which seem to reflect what they may have perceived as less, medium and more 'danceable' music (see description in Section 3.7.1). Although not statistically significant, it is suggested that the slow tempo (perhaps interpreted as a distinct 'slow dance style') provokes sparser cycles of movement by shifting periodicities from 2 beat length to 4 beats. On the other hand, a faster tempo tends to inuence the choreographies by shifting 4 beat length patterns to 2 beat lengths. The increase of rhythmical complexity and the decrease of time integration periods necessary to adapt to the rhythmic ambiguity may be taken into account in order to explain such changing from large to shorter repetitions. In addition, this trend reveals a bias to dance in a binary meter, which is easier when dance forms have a fast tempo.

Although other groups of gestures may deliver interesting observations over the variance and invariance of gesture in samba forms, hands and feet are the most evident compounds of dance forms in both visual (video inspection) and numerical representation (tracking data). Nose, shoulder, knee and hips were particularly subjected to deviation errors in the manual tracking, which may have resulted in random noise artifacts in the signal. This effect may reflect problems in the detection of non-precise 'points' in the natural silhouette. The shoulder, for example, is not

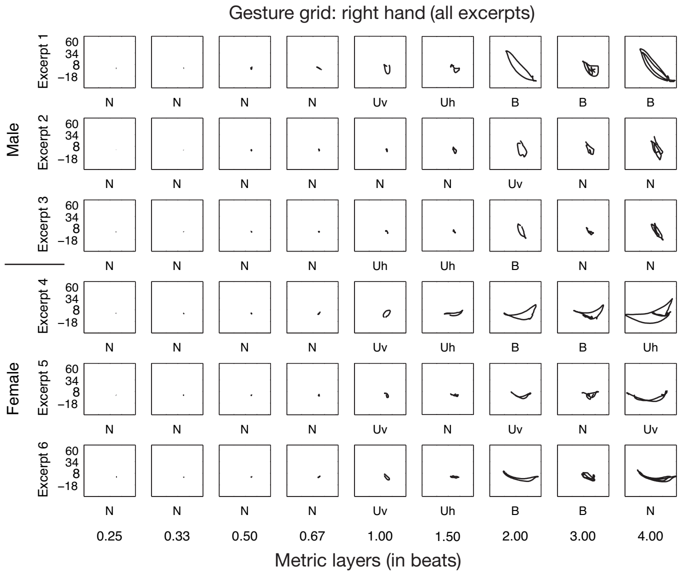


Figure 3.22: Grouped patterns representing left hand patterns. Rows from excerpt 1 to excerpt 3 are performed by the male dancer, rows from excerpt 4 to excerpt 6 are performed by the female dancer.

seen as a clear point in the body anatomy but a round contour extending from the clavicle to the forearm. Figure 3.25(a) and (b) show two complete sets of gestures performed in two dances. Metrical characteristics and contours of gestures are quite evident in the general inspection of the dance represented in the video.

One of the problems in representing feet movement of samba dance using this approach is that the displacement of points (marked down on a foot extremity) roughly represents the intention of foot rotation around the heel. A close inspection in the video shows more movement differences that may explain the different gesture trajectories between dancers. The movement of feet performed by the male dancer is often projected forward and rotated around the heel in the half part of the gesture cycle. However, in the dances performed by the female dancer we observed that her feet movements involve shorter projections ahead and a rotational gesture around the extremity of the feet. Although this explanation of differences is not properly described by our representations, the gesture grid of feet is able to capture relevance and metric and rhythmical engagement of overall movements.

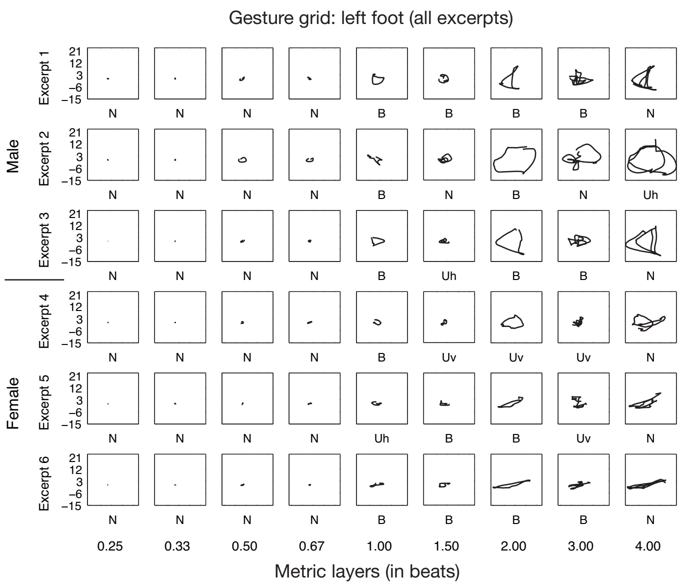


Figure 3.23: Grouped patterns representing patterns from left foot. Rows from excerpt 1 to excerpt 3 are performed by the male dancer, rows from excerpt 4 to excerpt 6 are performed by the female dancer.

3.9 General discussion

The goal of this paper was the presentation and illustration of a cross-modal method for the study of samba music and samba dance.

The core of this method is the use of musical meter as a lens to decompose body movement according to a proper periodic structure. The method is in agreement with an elaborate literature in which the samba culture is described as a form of human expression, in which music and dance are intricately related with each other (Sodré, 1979; Browning, 1995). Above all, our method is inspired by recent neurophysiological insights in the way in which humans handle periodicity when moving. Reference can be made to the hypothesis of a coupling between perception and action through a neuronal mirror-system (Rizzolatti & Craighero, 2004), and more specifically, evidence for strong 'period-based entrainment mechanisms between motor and auditory systems, similar to oscillators that become coupled in frequency to one another' (Thaut, 2005, p. 43). This hypothesis is based on the possibility of a direct projection of rhythmic time information as auditory perceived into rhythmic motor responses. Hence, it can be conceived as a kind of resonance system.

However, the embodiment of music may rely on different degrees of resonance behaviour, which range from simple synchronization to attuning (or re-enactment)

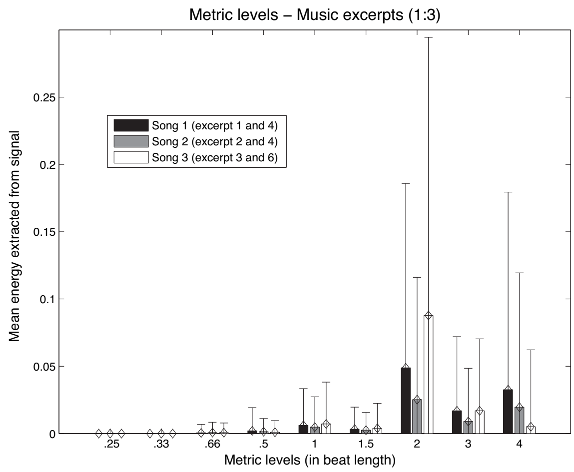
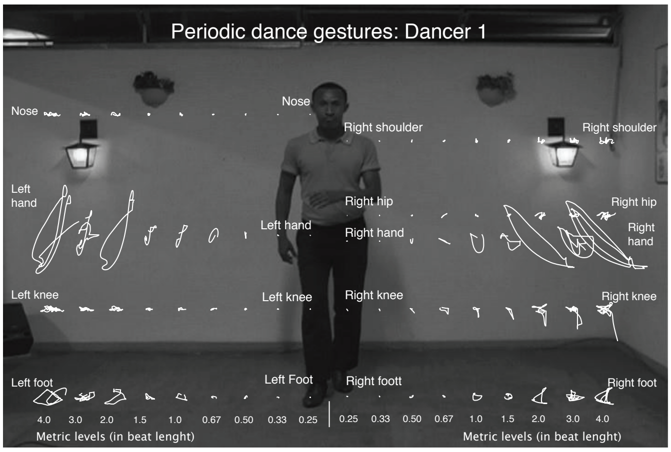


Figure 3.24: Mean energy and standard deviation of periodicities found in all body parts, all excerpts, across different stimuli. The same songs were performed by both dancers (see description in Section 3.7.1).

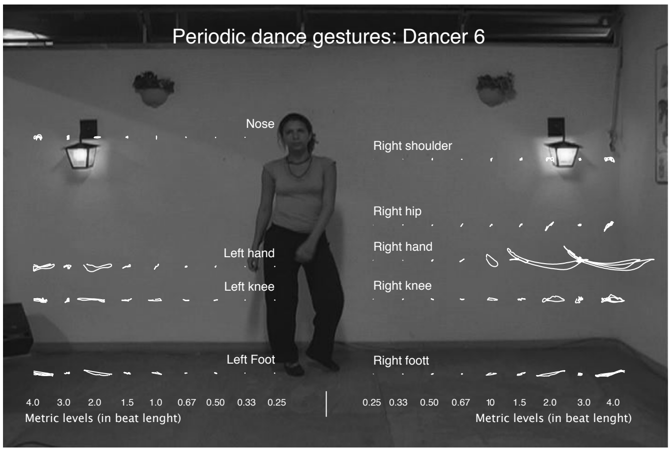
and empathic behaviour (Leman, 2007b). In samba music and dance, there are indications that the human body is involved in a consequent re-enactment of the samba meter. Re-enactment assumes an active role of the subject that responds to music.

Evidence for the re-enactment hypothesis is revealed by our cross-modal analysis, in particular by the finding that the meter in samba dance is not exactly the same as the meter in samba music (Figure 3.15(a) and (b)). Indeed, meter in samba music is characterized by periodicities that extrapolate the binary musical bar, showing quaternary and ternary metric tendencies (Figure 3.17). One may also point out an inherent rhythmical ambiguity, which further contributes to the overall confused and ambiguous metric character of samba music. In contrast with the music, meter in samba dances seems to suggest a different profile in which the binary beat layer gets a more prominent role (Figure 3.19). Our initial observations suggest that counter phase oscillations between mirrored body parts may reaffirm these symmetrical 2-beat movements. Spatial gestures not only are better defined in 2-beat layers, but gestures are more precise and strong in the affirmation of beat and 2-beat marks (Figure 3.22 and Figure 3.23). Further study is needed to figure out the precise nature of the rhythmic figures and interactions between body parts. It is likely that they may reveal interesting metrical constituents that reinforce oscillations in bar, beat and tatum levels.

Obviously, the cross-modal method is a starting point for further development in several directions. Our reenactment hypothesis implies that the samba dance in turn



(a)



(b)

Figure 3.25: (a) and (b) Complete set of metrical gestures in two dances. Metrical layers expand from the centre to the extremities of the figure.

contributes to perception through a disambiguation of the inherent ambiguity of the samba music meter. Disambiguation may well be the effect of the biomechanics of the human body, which imposes a certain motor structure onto an ambiguous auditory stimulus. The role of the body in this process may be a determining factor in meaning formation and subjective experience.

There are several ways in which the present study may be further developed.

A first direction is an improved motion capturing technology. While significant results can be obtained with video capturing, other methods, such as 3D-motion tracking systems (based on infra-red cameras) may provide finer details of the movement. Furthermore, we believe that our method can be easily extended to 3D motion.

A second direction is concerned with the study of a larger dataset for samba music and dance. We believe that our method can be applied in a straightforward way to an extended database of samba music and dance, and other styles as well, which is needed to test the reenactment hypothesis more thoroughly.

A third direction is concerned with a refinement of the cross-modal method and its associated heuristics itself. This method consists of a periodicity analysis and a heuristics. The periodicity analysis, based on the Periodicity Transform, was shown to be of interest within the context of music and dance analysis. The Any-and *Best-Route* heuristics allows a cross-modl approach based on a high-level structural concept, called musical meter. It was shown that this can be applied both to music and to dance. However, we believe that this method can be generalized further and that the metric framework can be used as a general method for the determination of periodicity in samba music and in dance, and perhaps also a number of other styles.

3.10 Conclusion

The present paper introduces a cross-modal heuristic for period pattern analysis of samba music and dance. This heuristics is based on the hypothesis of an intricate link between samba music and dance, which finds its origin in the meter, or metric structure. The periodicities that make up the meter are divisions and multiples of the beat, which is the basic periodic unit in the music.

The cross-modal heuristics developed in this paper is based on the Periodicity Transform, which allows the decomposition of a signal in terms of periodic patterns. The periodic patterns provide the period (time markers) and the waveform (deployment between time markers), as well as a measure of similarity with the original signal. These features can be used to describe meter in music and in dance. The method allows the comparison and detailed analysis of periodic patterns in music and dance. Dance movements in particular can be further studied using a reconstruction method that leads to Becking curves, that is, the description of the movement of a body part through its basic repetitive gesture.

The rationale behind the cross-modal method is based on the assumption of a tight coupling between perception and action, through which the dancer is somehow able to fully embody the musical meter. Although this embodiment may be conceived as a kind of resonance, we found that meter in samba dance is less ambiguous than meter in samba music. Hence the hypothesis that samba dance may rely on a re-enactment of the perceived samba music. This re-enactment is based on meter disambiguation, presumably determined by the biomechanics of the human body. Thus, while samba music and samba dance are tightly connected through a metrical structure that is inherent both in music and dance, this connection is not isomorphic. Instead, it is inuenced by the proper constraints of the human body and it is likely that these constraints may contribute to the pleasure and the ultimate experience of the music. The 'hunger for movement', which is provoked by samba music, is satisfied largely by binary repetitions of the human body, in response to poly-metric textures in music. The cultural context seems to rely on the inherent ambiguity of poly-metric textures, in order to activate participants to take part in the cultural act. Enacting, in such cases, allows music understanding. It is a constituent of the participatory context, and a central element in social interaction.

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4

Basic gestures as spatiotemporal reference frames for repetitive dance/music patterns in samba and Charleston

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Abstract

The goal of the present study is to gain better insight into how dancers establish, through dancing, a spatiotemporal reference frame in synchrony with musical cues. With the aim of achieving this, repetitive dance patterns of samba and Charleston were recorded using a three-dimensional motion capture system. Geometric patterns then were extracted from each joint of the dancer's body. The method uses a body-centered reference frame and decomposes the movement into non-orthogonal periodicities that match periods of the musical meter. Musical cues (such as meter and loudness) as well as action-based cues (such as velocity) can be projected onto the patterns, thus providing spa-

tiotemporal reference frames, or ‘basic gestures,’ for action-perception couplings. Conceptually speaking, the spatiotemporal reference frames control minimum effort points in action-perception couplings. They reside as memory patterns in the mental and/or motor domains, ready to be dynamically transformed in dance movements. The present study raises a number of hypotheses related to spatial cognition that may serve as guiding principles for future dance/music studies.

4.1 Introduction

Popular dance styles often are characterized by repetitive dance patterns that typically occur in synchrony with structures of the musical meter. In what follows, examples of repetitive dance patterns are taken from samba and Charleston dances. They can be seen as genuine instantiations of a large collection of dance typologies (often called popular, folk, or traditional dances) in which repetitive movements form an important part of the choreography.

In this paper, we explore the idea that repetitive dance patterns are based on spatiotemporal reference frames called basic gestures – that capture repetitive dance patterns in terms of a simple geometry onto which cues from music (e.g., meter, loudness) and body (e.g., speed) can be projected. Through the concept of basic gestures, we aim at developing a cross-modal approach that results in a representation that may contribute to a better understanding of the tight coupling of dance and music, and, in more general terms, the coupling of action and perception.

Dancing to music can be related to a general framework of embodied music cognition (Leman, 2007b). In repetitive dances, this includes body movements that occur in synchronization (and entrainment), as well as in counterpoint with, metrical properties of the music, such as the tempo and pulse of the beat, and multiples and divisions of the beat. In short, the embodied viewpoint entails the idea that dancing to music is an activity that strongly relies on the coupling of action and perception, and that the human body plays an important role as a mediator that couples subjective experiences with the physical environment.

When studying dance patterns in relation to music, there is a need for detailed descriptions. Analysis techniques have been developed that capture features of dance patterns as objective time-varying structural descriptors, such as the quantity of movement and the contraction index[1] in video analysis (Camurri, 2002; Camurri et al., 2003, 2004; Glowinski et al., 2009; Guedes, 2006). However, these time-

[1] The contraction index is inspired by Laban’s notion of a kinesphere (Laban & Lawrence, 1947; Laban & Ullmann, 1966, 1980), which is a hypothetical space defined by the extremities of the human body posture, reminiscent to Leonardo da Vinci’s Vitruvian man (Counsell, 2006). The contraction index is calculated as the ratio between the area of the object’s silhouette and the area of object’s bounding rectangle. As the dancer moves, the parameters of the contraction index move along as time-varying variables.

varying structural descriptors say little about the dancer's interaction with music and space. To uncover these relationships, a correlation analysis of the time-varying structural descriptors of movement in relation to musical features is needed, but this is difficult if no cross-modal representations of the coupling between these domains are available.

In parallel with the development of video analysis platforms and tools, some empirical studies on dance have focused on the extraction of time-varying variables from motion capture systems and motion sensing systems (Bevilacqua et al., 2002; De Bruyn et al., 2009; Eerola et al., 2006; Shiratori et al., 2003; Yamamoto & Fujinami, 2008). So far, mainly aspects of movement synchronization and movement intensity have been considered, and little attention has been devoted to the spatiotemporal development of the dance patterns. Many researchers therefore will agree that the study of dance/ music couplings is still in an initial stage, and that there is a lack of concepts and tools that can define the coupling of dance and music within a unified framework.

We believe that the concept of basic gesture may offer a particular contribution to a spatiotemporal framework that allows the study of repetitive dance patterns in close relation to musical cues. In this context, it is important to mention that the concept of basic gesture is intended to provide a viewpoint on action-perception couplings that is conceptual rather than physiological. As such, it may be related to three different representational domains. First, a basic gesture may be related to the mental domain, where it would function as a mental representation, possibly defined as an image, of a spatiotemporal reference frame for repetitive dance patterns. Second, a basic gesture may be related to the motor domain, where it would function as a motor schema; that is, a frame of reference or disposition for motor activity in response to auditory input. The difference between mental representation and motor representation is that the latter would typically require less memory load at the moment when the intentional action is physically carried out. And finally, a basic gesture may be related to the executed dance pattern itself, or even better, to a trajectory of the body movement as physically deployed in space and time. These three viewpoints play a role in our current thinking about musical gestures (see Godøy & Leman, 2010). The idea that a gesture may manifest itself 'out of time'that is, as a representation of a reference frame for action-perception, is crucial to explain why we speak about 'gesture' and not just about 'body movement' (Leman & Godøy, 2010).

Given the framework described above, it is possible to adopt an empirical approach in which basic gestures are reconstructed from physically deployed repetitive dance patterns. In this approach, a physical repetitive dance pattern is seen as the execution of a mental and/or motor pattern, whose particularity lies in the fact that it is the representation of a frame of reference that aligns body movement with musical cues.

Thus, in the present study, we focus on how dancers deploy repetitive dance patterns in synchrony and counterpoint with musical cues. A method is described that allows the re-construction of basic gestures from these repetitive dance patterns. The method is based on a number of assumptions (outlined below) that may serve as guiding principles for future dance/music studies. Although our main target is to show that a basic gesture can be represented as a geometrical shape onto which music cues (e.g., related to timing, loudness) can be projected, it will be straightforward to extend the method to action cues (e.g., speed) as well.

By concentrating on the analysis of individual dancers, we hope to be able to develop an approach that represents both the general and the particular: the generality is related to the description of a global concept of basic gesture as representational structure of a spatiotemporal reference frame for action-perception, whereas the particularity is related to the assumption that musical styles have their proper reference frames, and that dancers have their proper gestural characteristics.

4.1.1 The concept of basic gesture

The concept of a basic gesture can be traced back to Becking (1928), who described the general form of sympathetic movements in response to music as a kind of geometric shape that summarizes the trajectories of a repetitive pattern (Becking, 1928; Nettheim & Becking, 1996).

Becking's concept of basic gesture is still relevant to studies in which a motion capture system measures kinematic aspects of dance movements. Starting from physical movements, a basic gesture can then technically be defined as the three-dimensional movement pattern of a body part during one period of a repetitive dance sequence. One should add that the measurement by a motion capture system is actually limited to the measurement of fixed points (so-called markers) on the body but doesn't measure the entire body movement. Furthermore, two considerations concerning shape and timing should be taken into account, which somehow frame (and thus confine) our current concept of gesture. The first consideration is that the shape of a basic gesture (more specifically, the three-dimensional trajectory of one period of a repetitive movement of a fixed point on the body) will be such that its starting point and ending point will be connected. Otherwise, it cannot be considered to be repetitive. The second consideration takes into account the timing of the gesture, which, we assume, is related to the natural frequencies (or eigenfrequencies) at which body parts tend to move. For example, repetitive movements of legs during walking can characterize a basic movement, because these movements are repetitive and their timing is related to the biomechanics of the human body (Styns et al., 2007). The basic gesture is called 'basic' because it appears as an ideal reference frame for matching spatial and musical cues in a movement configuration that requires little effort to maintain its repetitive character

(Van Noorden et al., 2010). The situation is similar to a pendulum, where the swaying can be maintained with little input force, provided that the period of the latter fits with the resonance frequency (the eigenfrequency) of the pendulum. The reference frame would specify that the extremities of the pendulum movement would correspond to the beat of the music. There are several studies on tapping along with music (Van Noorden & Moelants, 1999), walking on music (Styns et al., 2007), spontaneous movement without music (MacDougall & Moore, 2005), and music-driven group synchronization (De Bruyn et al., 2009; Van Noorden et al., 2009) that suggest that this resonance frequency lies in the vicinity of 2 Hz (which equals 120 beats per minute (bpm). However, there is a broad range of musically relevant beat frequencies from 30 to 240 bpm (London et al., 2006) that may be considered relevant. In short, basic gestures are assumed to have a simple geometry (a three-dimensional line that is connected), and a simple timing basis (related to the body's resonance frequency). Their geometric description is called a Becking curve.

4.1.2 Basic gestures and musical meter

Styns et al. (2007) explored the concept of basic gesture in studies on how people walk to the beat of the music. He focused on the speed of walking in relation to the musical tempo (i.e., beats per second). In a series of studies on samba dance and music (Naveda & Leman, 2008a,b, 2009), this concept of basic gesture was further developed and was related to the hierarchical structure of musical meter. The latter consists of multiples and divisions of the beat period. The approach was based on the idea that movement can be studied by using the musical meter as a gauge. It introduced a crossmodal method in which a metrical grid (defined with respect to multiplications and divisions of the musical beat) was used to select body movement periodicities (see Figure 4.1). The method uses a heuristic based on periodicity transforms (Sethares & Staley, 1999) that produces a map of repetitive patterns in dance similar to the Becking curves (Becking, 1928). This leads to a spatial representation of basic gestures, onto which additional indication of the timing of the metrical grid can be projected. It was shown that basic gestures can be extracted straightforwardly from repetitive dance patterns, and optimal solutions are obtained when the musical metrical grid fits with the repetitive period of the dance patterns. As such, the basic gestures can be related to the time points of the meter (double beat, beat, half beat, quarter beat, etc.), thus providing a spatiotemporal representation of repetitive dance gestures.

Using this analysis approach, Naveda & Leman (2009) found evidence that (binary) periodicities in the gestures of the samba dancer may disambiguate the metrical ambiguity (binary versus ternary groupings of the beat) in samba music. The process of corporeal-based disambiguation can thereby be seen as a meaning

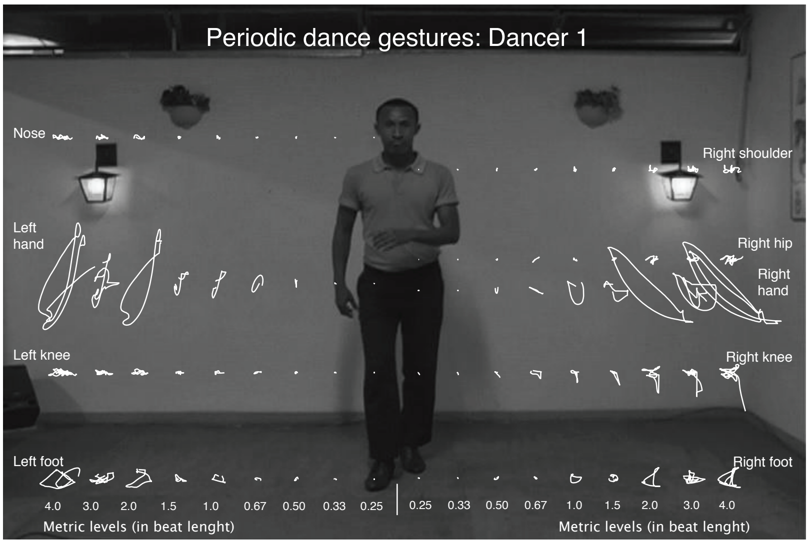

Figure 4.1: Samba dancer and becking curves associated to different body parts (Naveda & Leman, 2009, p. 279). The becking curves represent the shapes of basic gestures, of which the period corresponds to the period of the metric grid (horizontal). Note that the becking curves are not always closed, which is due to the method used in Naveda & Leman (2009).

formation process that is rooted in the deployment of the body, rather than by mere mental processing of sonic structures (Leman, 2007b; Phillips-Silver & Trainor, 2007).

However, the approach described in (Naveda & Leman, 2009) had two major limitations. First, it was based on the analysis of video recordings of dance, and therefore, the extracted patterns were two-dimensional. Second, the method considered body movement (and basic gestures) from the viewpoint of an absolute reference framework that is defined by the video recording position. The latter implies that from a different observation position, different basic gestures are extracted. Instead, what is needed is an analysis that considers (i) three-dimensional representations of basic gestures, and (ii) representations that are invariant with respect to the observation position. The shift from two dimensions to three dimensions can be obtained with a motion capture system. The shift from absolute reference framework to a relative reference framework, however, affects the representational nature of the basic gesture in the sense that it changes the viewpoint from observer to dancer. The relative framework is therefore called a body-centered reference framework, and it refers to the peripersonal space (i.e., the space surrounding our body that can be reached by our limbs) around the dancer.

The following three assumptions summarize the starting position for our current study of basic gestures. The first assumption states that movements of all body markers in free space (viewpoint of the observer) can be related to the geometrical centroid of the dancing body, so that all movement trajectories can be linked to the dancer's body-centered frame of reference. The second assumption states that dance movements are consequences or inductors of the metrical structure of the music, and it implies that a musical metrical grid can be used as a gauge to look at body movement. The third assumption states that repetitive dance patterns rely on reference frames that are related to the eigenfrequency of the body, and for that reason, these reference frames require less effort. What follows is a description of a method that takes these assumptions into account.

4.2 Method

4.2.1 Experimental setup

The dancers wore a dance suit with 34 reflective markers attached to it; the markers provided the point-set representation of body morphology. The markers were placed on: head (3), upper arms (3 + 3), upper back (3), hips (4), hands (3 + 3), thighs/knee (2 + 2), shins (1 + 1), and feet/toe (3 + 3). The stimulus used to perform the samba dances (professional dancer and students) was composed of looped samples of a samba percussion ensemble (*surdo*, *tamborim*, and *caxixi*). The samples were recorded from professional samba musicians in Brazil, using a multitrack recorder. The stimulus used to accompany Charleston dances was composed of phrases of Charleston music ("Novelty Charleston,"Titanic Ensemble). The bpm was 90 for the samba stimulus and 111 for the Charleston stimulus.

The movement recordings were recorded using an Optitrack system (Natural Point) composed of 12 cameras positioned around a squared aluminum structure (6 x 6 square meters). The duration of each take was approximately 60 s at a frame rate of 100 Hz. The recordings were synchronized with audio using movement cues performed by the subject in synchrony in predefined audio onsets played at the beginning of the audio stimulus.

4.2.1.1 Subjects

Two professional dancers/teachers and one dance student participated in the experiments (all females). The Charleston dancer was a professional Dutch dancer/teacher who specialized in old and traditional dances and had several years of experience in performance and teaching. She performed dances in basic Charleston style.

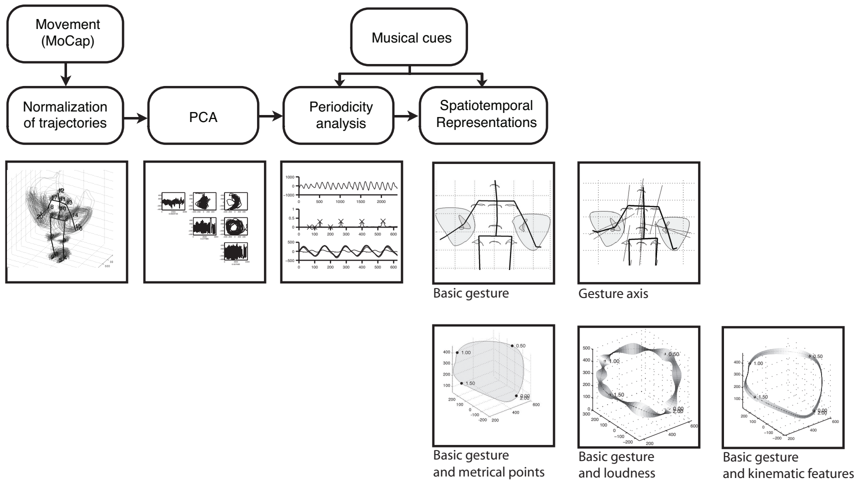

Figure 4.2: Illustrative flow chart describing the methodology used in the data analysis. On top, the movements are recorded by a motion capture system (Mocap) and the musical cues are presented. The second row from top displays the processing flow. The figures in rectangular boxes show the resulting images at each processing stage.

The samba dancer was a Brazilian female dancer/teacher who specialized in Afro-Brazilian dances and had several years of dance experience in performance and teaching. She performed dances in the "Samba-no-pé" style, which is the main substyle of samba dances. The student of samba dance was a Belgian female dance amateur, with 1.5 years of experience in samba dance (lessons). The lessons were taken with the same professional dancer who danced in this experiment.

4.2.1.2 Task

The dance excerpts used in this study had different lengths. The dancers were asked to perform examples of the basic dance forms within a defined circular area (diameter = 4 m) in a relatively isolated environment. They were asked to avoid unnecessary turns in the body orientation (frontal performance, in relation to a single direction).

4.2.1.3 Material

The recording sessions were edited and exported as C3D files using the software ARENA (Optitrack/Natural Point). The sequences were imported into Matlab using the MoCap toolbox (Toiviainen & Burger, 2010). The calculation of body-centered segment positions, filtering of raw vectors, normalization, and part of the visualization functions, were also based on the MoCap Toolbox.

4.2.2 Data analysis

The data analysis consisted of a chain of processes that involve normalization, principal component analysis, and periodicity detection (see Figure 4.2). First, the trajectories in free space were normalized in order to obtain movement data in the peri-personal space. Then, a principal component analysis (PCA) was applied to the data in order to determine the dimension (or coordinate) that captures the largest variance of the gesture's trajectories. In this dimension, a periodicity analysis is carried out, using the musical grid from the musical stimulus as a guide for searching the periodicity. The shape and periodicity of the gesture was then reconstructed from the other dimensions onto which musical cues and action cues could be projected. Figure 4.2 shows a schematic overview of the processing and its results.

4.2.2.1 Normalization of trajectories

The raw data from the motion caption recordings appear in an arbitrary coordinate system (X, Y, Z) with a fixed reference point that was defined during the setup of the motion capture system. From these raw data, body-centered representations could be obtained by relating the recorded trajectories of the joints of the body parts to a single point on the dancer's body. The point of reference was defined as the centroid of the markers on the body. In addition, the orientation was defined as frontal with respect to the left and right hips. The trajectories of all joints was then related to that moving body point, rather than to a fixed arbitrary reference point. This operation, called normalization, resets the coordinates of the joint positions, rotations (turning around of the body in physical space), and translation (displacement of the body in space) for each frame of the recording.

Figure 4.3a shows the raw trajectories of repetitive movements of samba dancing, which become visibly less dispersed after normalization in Figure 4.3b. The figure shows movement trajectories in the peripersonal space of the dancer. The general form of these trajectories is ordered. This suggests the existence of redundant patterns of movement that can be perceived as simplified geometries, or Becking curves, such as circle-like figures.

4.2.2.2 Principal component analysis (PCA)

After normalization, we apply a PCA to the trajectory of each joint. This was done in order to find the dimension where the movement was largest. For each joint, the best perspective for further periodicity analysis was then obtained by a rotation

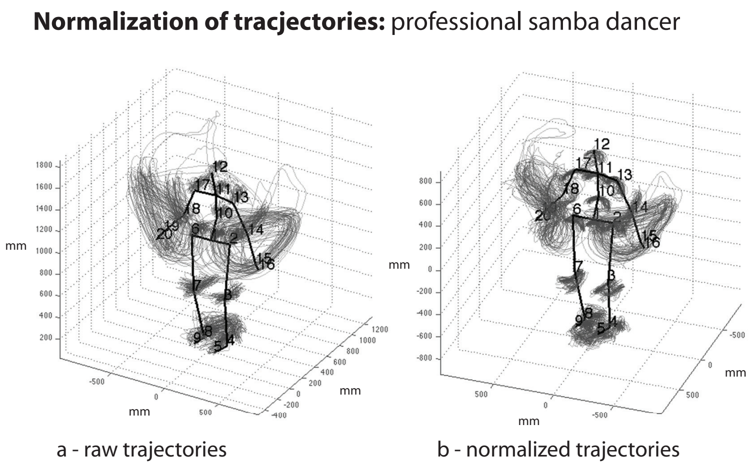

Figure 4.3: Movement trajectories of the samba dance for 16 joints. (a) The movement trajectories of repetitive dance patterns in free space (raw data). (b) The normalized movement trajectories.

of the trajectory, using the eigenvectors of the PCA analysis. Figure 4.4 shows the original trajectory description of a repetitive gesture of the hand, measured by means of the joint position of the hand (derived from three markers placed on the hand) and the rotated version of the same trajectories, oriented to display the largest movements in the component dimensions. One can observe that the repetitive pattern occurs in a slightly curved plane, whose main axes are defined by the (two main) principal components.

4.2.2.3 Periodicity transform

To extract the period and shape of a basic gesture from each (PCA-rotated) movement trajectory of a joint, we decomposed the trajectory into a set of basic periodic bases. This decomposition is based on the periodicity transform (Sethares & Staley, 1999), which finds periodicities and bases of periodicities in the original signal, together with respective measures of energy (also called: norm). Unlike other methods such as Fourier or Wavelet transforms, the periodicity transform (PT) does not make any assumptions about the shape of the basic gesture (see discussion in Naveda & Leman, 2009, p. 260). However, the results of periodic decomposition are non-orthogonal, which implies that a given periodic basis obtained from a periodicity transform projection is not independent from other periodic bases obtained from the same trajectories (such as in Fourier or wavelet transforms). Different heuristics, different orders of projections, and subtractions of basic period patterns from the signal will lead to different results.

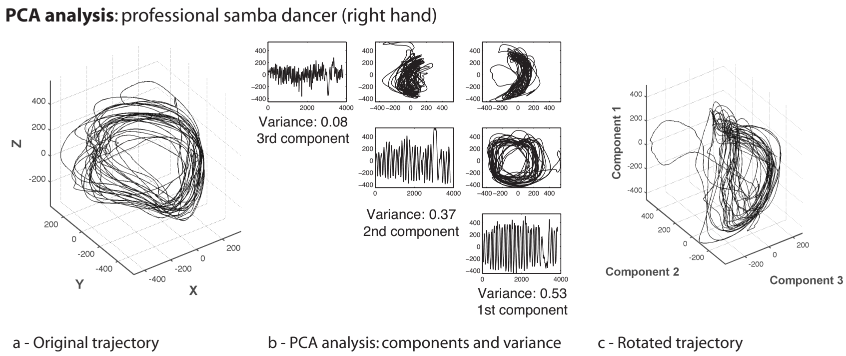

Figure 4.4: Movement trajectories of the right hand. (a) The original movement trajectory in a coordinate system that is system dependent. (b) The PCA components and variances (ratio of the total variance). (c) The rotated movement trajectory, which is dependent on the variability of the movement (axes display units in mm).

A proper heuristic for the decomposition of repetitive dance patterns can be based on the assumption that musical meter can be used as a gauge to look at the periodicity in dance patterns. In practice, each metrical unit (i.e., the beat, and its multiples and divisions) has a duration, or time period, which defines a sieve (a small time window in the vicinity of that time period), through which we look at the repetitive dance pattern in order to apply the periodicity transform. The period (and corresponding shape) of the repetitive dance pattern is extracted using the *Any-Route* heuristic (Naveda & Leman, 2009), which uses a strategy in which each sieve-based search starts from the original signal. Alternatively, one could use a heuristic where the most prominent period is first extracted from the signal, and less prominent periods are subsequently extracted from the residues of that signal (as in the *Best-Route* heuristic in Naveda & Leman, 2009). Owing to the fact that the *Any-Route* heuristic starts from the original signal for each period of the metrical grid, this heuristic will find the maximal shape of a particular meter-related period in the dance pattern. The *Any-Route* heuristic provides a description of the metrical ambiguity of the original signal.

The periodicity analysis, using the periodicity transform, is then applied to each dimension that constitutes the movement trajectories. We thereby assume that the dimension with more variability in the movement trajectory (i.e., larger movements) should guide the periodicity analysis towards the other two dimensions. By using this approach, the detection of the periodicities in the other two dimensions is somehow forced.

It is important to consider that this approach entails two assumptions that

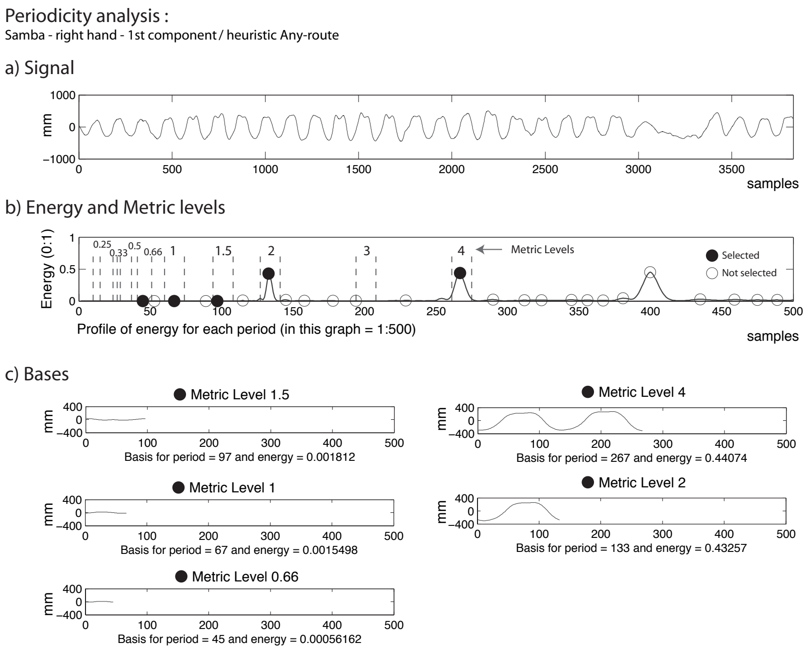

Figure 4.5: Periodicity analysis applied to the dimension where the variability of the movement trajectory is largest. (a) Top panel: The original signal (here: a displacement of a body part represented in one single dimension). (b) Below top panel: periodicity analysis with indication of the metrical grid. (c) Bottom panels: extracted bases, corresponding to the selected periods of 0.66, 1, 1.5, 2, and 4 times the beat. According to the *Any-Route* heuristic, each shape is extracted from the original signal.

influence the detection of periodicities in the PCA-transformed trajectories. The first assumption is that it looks only for periods in the repetitive dance pattern that belongs to the metrical structure of the music. The second assumption is that it extracts the period from the dimension where the repetitive dance pattern displays the largest movements. The periodicities in this dimension are then used to retrieve periodic patterns in other dimensions, so that a basic three-dimensional gesture (consisting of period and shape) can be reconstructed.

Figure 4.5 displays one example of the periodicity analysis (*Any-Route* heuristics), applied to the first principal component of the hand trajectory (from the same trajectory described in Figure 4.4).

The top graph in Figure 4.5 displays the original signal in the dimension where the variability of the movement trajectory is largest. The second graph displays the metric grid (dashed lines) and the profile and peaks of energy of periodicities (periodicity/signal energy ratio), which are computed using the periodicity transform over all periods. The lower graphs show all the bases of the periodicities selected. These bases reflect the metrical ambiguity of the signal (as an outcome of the non-orthogonal method). Note also that in this example, the four-beat basis does not add any new information to the two-beat basis.

Figure 4.6a and Figure 4.6b show the result of a periodicity analysis for a samba dance and a Charleston dance pattern. The dancer is represented as a stick figure. For each body part, the percentages of the variances are graphically shown, related to (i) the peripersonal space where the X (left-right), Y (up-down), and Z (back-front) dimensions are shown, and (ii) the principal components of each joint, which reveal the dimensionality of the joints where the gesture is largest. The last column (iii) shows the profile of energies of each extracted metrical period (number 1 stands for the beat), which is defined as the ratio between periodicity and signal energies. This profile indicates which level of the musical meter is likely to be the fundamental period of the movement. The algorithm is defined in such a way that the period with the highest energy value is selected as the period of the basic gesture, of which geometries are shown on the stick figure (see next sections for further explanation of how these geometries are obtained). Note the differences between samba and Charleston: in samba, the basic gesture is two-beat (a four-beat basis has the same value), whereas in Charleston, the basic gesture is four-beat (highest value). The figure also provides information about the direction of the movements for each joint; for example, the tendency for diagonal movements in the hands of the samba dancer (rfinger) or the tendency for left-right movements in the hands of the Charleston dancer. The data suggest that in Charleston dance, basic gestures evoke a single dimension(X: left-right, Y: up-down, Z: back-front), whereas in samba dance, basic gestures evoke two dimensions.

4.3 Analysis and discussion

4.3.1 Reconstruction of a basic gesture

Based on the analysis method described above, it is now possible to reconstruct the basic gestures. Figure 4.7a shows the basic gestures that can be extracted from the repetitive movement pattern of Figure 4.5. The gestures are shown on a metrical grid, representing metric levels of 0.25 to 4 times the duration of the beat. The amplitude of the gesture shapes shows the level of (the non-orthogonal periodicities') response, for each metrical grid. This can be interpreted as the likelihood of the basic gesture occurring at that metrical unit. The size of each shape thus indicates how likely it is that this shape underlies the movement trajectory. As shown in Figure 4.7 (top), the most likely period corresponds to two beats. This gives the most compact gesture, since the gestures at metric level 4 already contain repetitions of this basic gesture

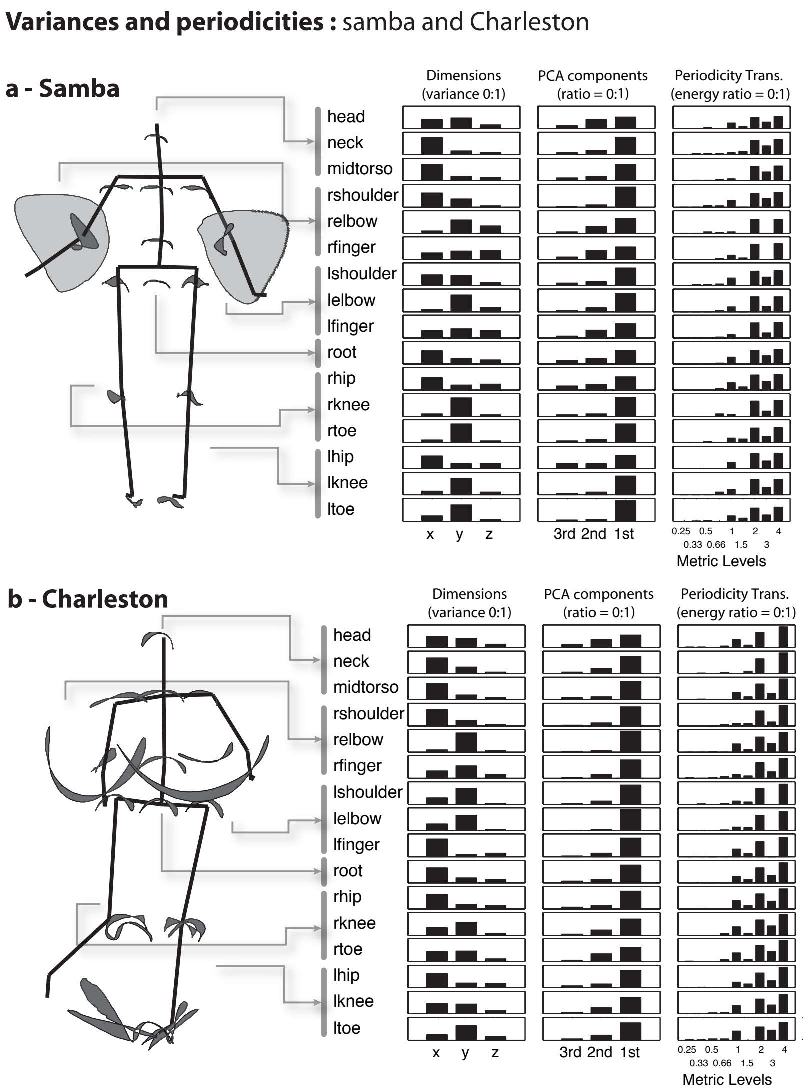

Figure 4.6: (a and b). Stick figure (and basic gestures) with (i) levels of original variance, (ii) levels of variance after PCA, and (iii) energy ratio for periodicities, for both samba (a), and charleston (b). The level of variance is defined as the proportion of the variance of each dimension with respect to the sum of variances of all three dimensions. The energy ratio indicates an average of the energy in each dimension, calculated as the norm or inner product of the periodic pattern with the signal. With the *Any-Route* algorithm, periodicities at one level may include periodicities found at other levels.

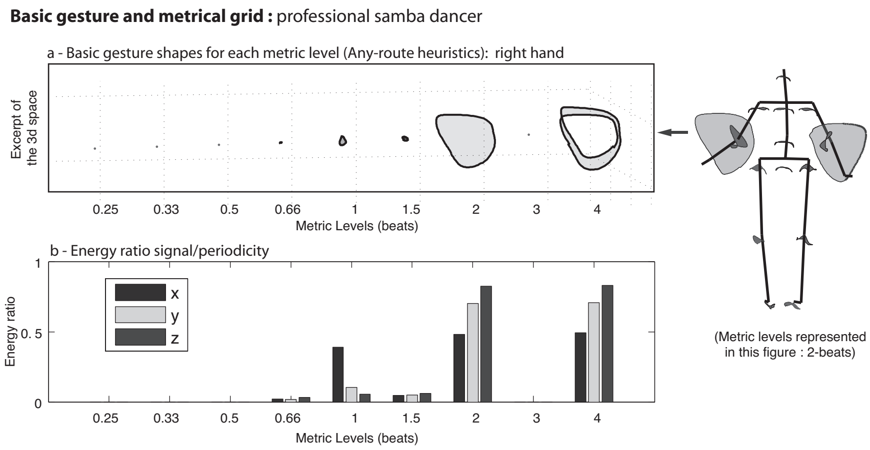

Figure 4.7: (a and b) The top panel shows the basic gestures of the hand movement shown on a metrical grid. The numbers below each shape define the metrical grid in terms of the musical beat, of which the period is defined as the unit. The bottom panel displays the evidence for the periodicity decomposition showing the energy ratio for each dimension of each basic gesture after the PCA and periodicity analysis.

and almost the same energy ratio (bottom).

4.3.2 Basic gestures of samba and Charleston

The above method enables us to compare the repetitive dance patterns of samba and Charleston dance. Figure 4.8 (samba) and Figure 4.9 (Charleston) show 16 basic gestures selected from 20 original joint trajectories [2] in connection to a stick figure that is taken from a random frame of the dance sequence. These joints are extracted from a triangulation of the skeleton of 34 markers, described in the methods section (see Toiviainen & Burger, 2010, for more information about this process).

In samba, the gestures are represented at a period of two times the duration of the beat (two-beats metric layer), which seems to be the fundamental element of the metrical gesture palette (see Figure 4.7) and also the characteristic bar level of samba music. The basic gestures of the hands are more pronounced than the gestures of the other body parts; this does not necessarily mean they are more perceptible

[2]Joints (and short names) selected for the calculation of basic gestures: root (root), left hip (lhip), left knee (lknee), left toe (ltoe), right hip (rhip), right knee (rknee), right toe (rtoe), mid-torso (midtorso), neck (neck), head (head), left shoulder (lshoulder), left elbow (lelbow), left finger (lfinger), right shoulder (rshoulder), right elbow (relbow), right finger (rfinger).

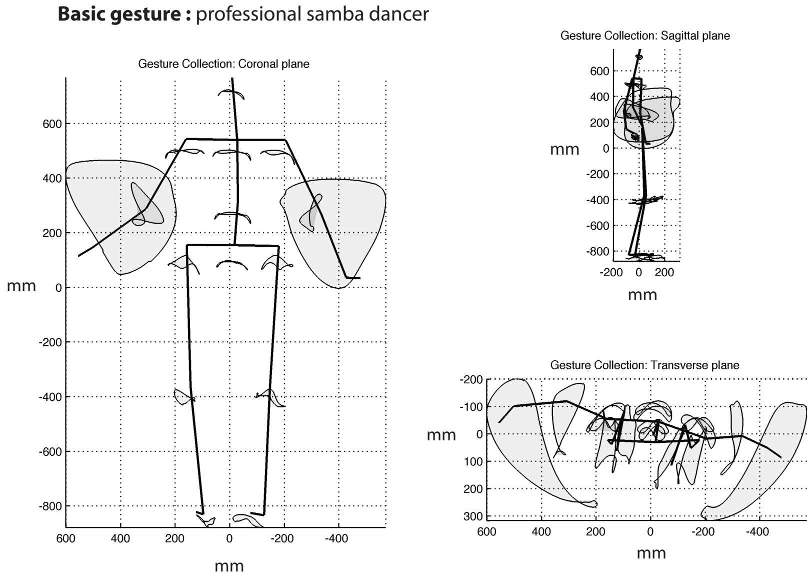

Figure 4.8: Basic samba gestures for different body joints. The metric level is two-beat. The internal area of each shape is indicated by a transparent gray value so that superposition of shapes in an angle of vision can be intuitively perceived (a gesture shape behind another will appear darker than a gesture shape in the front). The representation of the dancers' body (stick figure) is taken from a random frame (it only represents a snapshot of the dancer's body in time).

or important for the dancer. Hands move more but represent a small part of the total mass of the dancer's body. Less pronounced movements, such as the head and torso, are linked with a considerable proportion of the body mass. Movement of the torso and head in the samba dance exhibits a considerable similarity concerning shape and amplitude, which may be explained by the morphological constrains of these parts.

The basic gesture of the Charleston dance is displayed in Figure 4.9. Even with the normalization of trajectories in relation to the body, we observe that Charleston gestures are more extended than samba gestures. The areas inside the basic gestures indicate how the extension differs in terms of the occupation of space. The space inside of the Charleston hand gestures is thinner than the space inside the samba hand gestures, and paths are almost superimposed in an arc-like shape. Feet gestures, which are characteristically ample in Charleston dances, demonstrate similar arc-like geometries. This similarity is reinforced by the gestures of the torso, which seem to be shaped by arched geometries as well. Again, like in samba, shapes

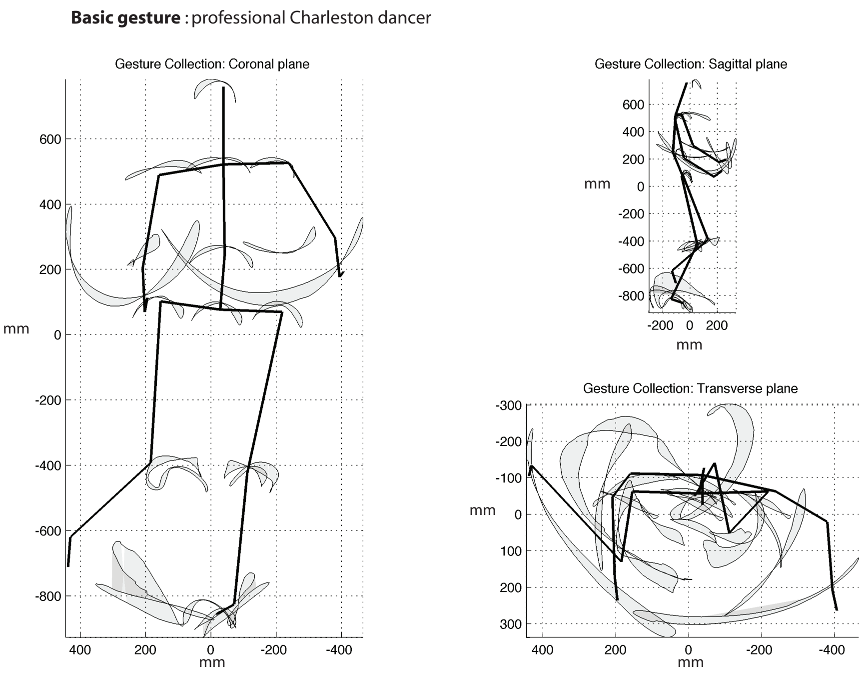

Figure 4.9: Basic gestures from Charleston dance for different body joints (from a two-beat viewpoint).

of the torso and head are similar and symmetrical, even though the center-extremity trend found in the size of the basic gestures in samba is unclear in Charleston. In order to simplify the display, Figure 4.9 shows the basic gestures from the two-beat viewpoint. As mentioned, there are reasons to consider Charleston patterns from a four-beat viewpoint. This is of particular relevance for the foot patterns.

4.3.3 The gesture axis

The curved plane in which the gesture is represented can be linked in a direct way to the body-centered frame of reference. For that reason, it is straightforward to introduce the concept of a **gesture axis**; that is, a virtual axis that connects the body-centered perspective to the gesture. The gesture axis represents the body-centered perspective from which the control of the movement is likely to be most effective in terms of shape and variability. This representation of the gesture axis is obtained by plotting a line perpendicular to the first two principal components (or parallel to the third component), passing through the geometrical centroid of the basic gesture. Figure 4.10a shows the basic gesture and its axis as an isolated unit. Figure 4.10b

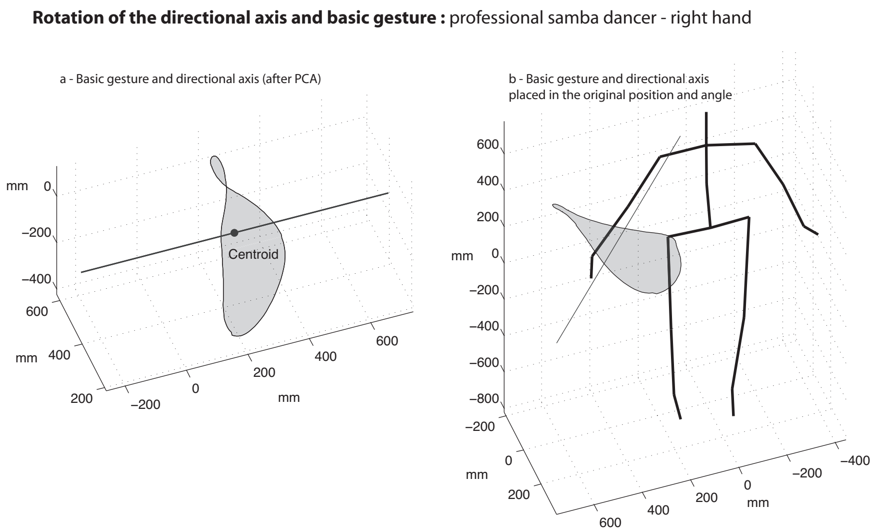

Figure 4.10: Representation of the gesture axis. (a) Basic gesture and perpendicular line through the centroid of the basic gesture, which represents the gesture axis. (b) The basic gesture and its gesture axis at its original position in relation to the representation of dancer's body.

shows this unit in conjunction with the skeleton of the dancer.

Figure 4.11 demonstrates the application of the concept of gesture axis to 16 joints on the body of the samba dancer (teacher). Interestingly, the slightly negative angle of the axis of most of the gestures, as seen from a two-dimensional rotational viewpoint in the coronal place, seems to indicate an inclination bias of the whole body. In addition, the symmetry observed in the shapes of the basic gesture is repeated in the gesture axes. Figure 4.12 shows the same result for the Charleston dance, which seems to offer a contrast to the systematic symmetry found in both gestural shape and orientation in samba.

In Charleston dance, displayed in Figure 4.12, symmetries are not as clear as in samba, although some trends may be found. Given the fact that Charleston dances encompass larger whole body movements, including jumps, the normalization of the trajectories may have imposed artifacts to the geometry of the gesture. Another explanation is that the dances or dancers' morphologies are simply different, or that the technical orientation of dance techniques is distinct. Further research is needed to better understand this issue.

The orientation of feet gestures is approximately perpendicular to the ground. The angle of hips and knees follow the bending tendencies of the leg, while head and shoulders are aligned with the torso. It is informative to compare the basic gesture map of the expert samba dancer in Figure 4.11 with the basic gesture map

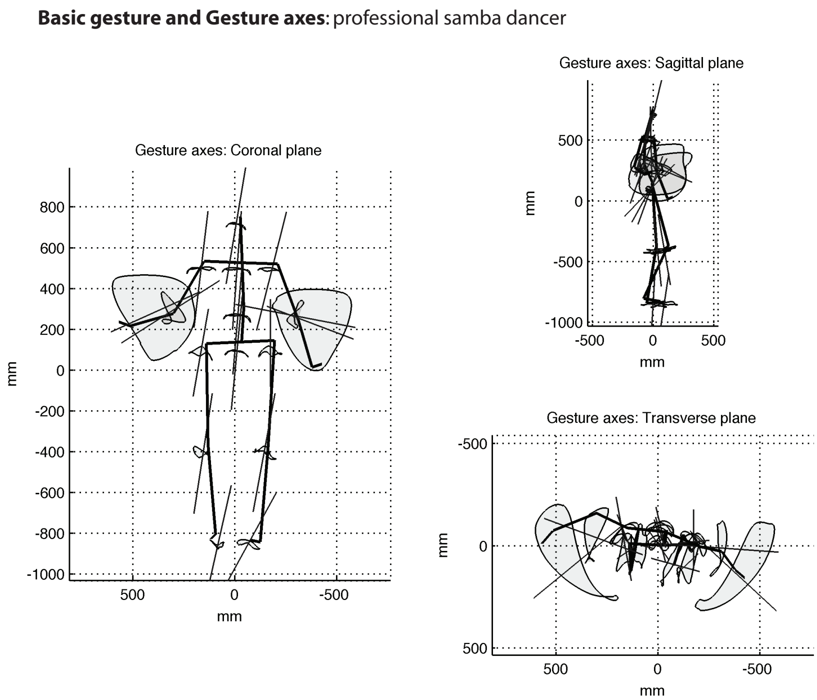

Figure 4.11: Representation of the dancer's body (professional samba dancer) displaying basic gestures and gesture axes for 16 joints.

of the novice samba dancer of Figure 4.13.

Figure 4.13 shows the gesture axes of a student of samba dance. These axes seem to display less internal symmetry (symmetry between axes) than the gesture axes of the dancer teacher depicted in Figure 4.11. The differences may indicate that symmetry and parallelism between the directional angles of the gestures can play an important part in mastering stylistic forms in samba dances.

4.3.4 Linking basic gestures to musical features

The basic gesture, which captures the repetitive movement trajectory over time, can be superimposed with any musical cue derived from the synchronized audio signal. This is useful for studying the intricate relationship between dance movements and musical features. Two straightforward links are (i) time points, and (ii) loudness.

4.3.4.1 Linking basic gestures with timing points

The subdivision of the time domain vectors in discrete points representing metrical steps (e.g., 0.5 or 0.25 beats) will lead to a linear subdivision of the three-

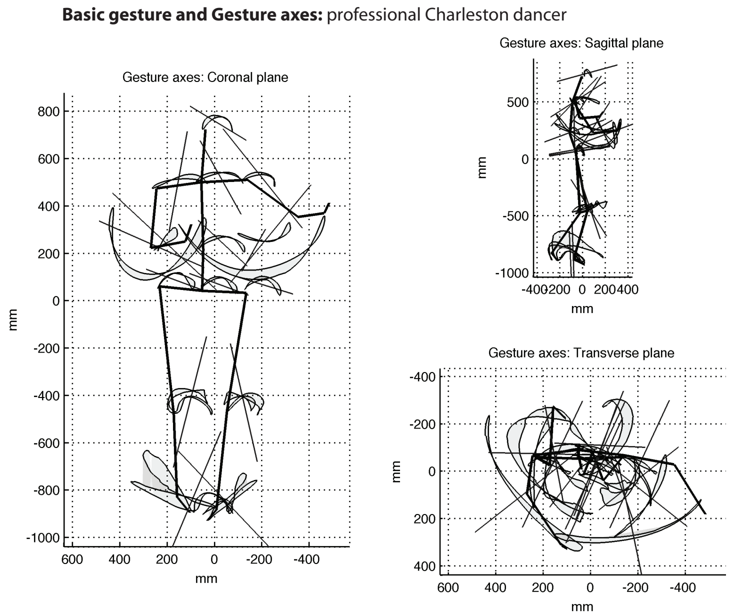

Figure 4.12: Representation of the dancer's body (professional Charleston dancer) displaying basic gestures and gesture axes for 16 joints.

dimensional space in the same metrical steps, which appear now as trajectory steps from one spatiotemporal reference point to another. The computation of this feature is rather simple since the sample position of any point in time will provide the position of the segmentation point in space. However, the procedure allows observing how meter unfolds as dance forms by indicating the spatial locus, direction, and organization of musical meter along redundant trajectories. Figure 4.14 shows two examples of segmented gestures from samba and Charleston dances, both in the metrical level two-beats. The examples show the three-dimensional vectors that compose the bases of periodic gesture trajectories obtained from the periodicity analysis, segmented in steps of 0.5 beats and the concatenation of the three dimensions in a three-dimensional view.

This kind of visualization can unravel several interesting elements of the deployment of the dance gesture in time. The hand movement of the samba dancer, for example, signalizes each 0.5 beat step with a round and soft turn, making the gesture almost square-like form. It is possible to observe that the horizontal separation between signalization points is larger than the vertical separation of these points, which seem to indicate that metrical structures may be grouped in two horizontal metrical segments, 0.0-0.5 and 1.0-0.5. The hand movement of the Charleston dancer describes an arc gesture, but the beat or half beat points are not directly

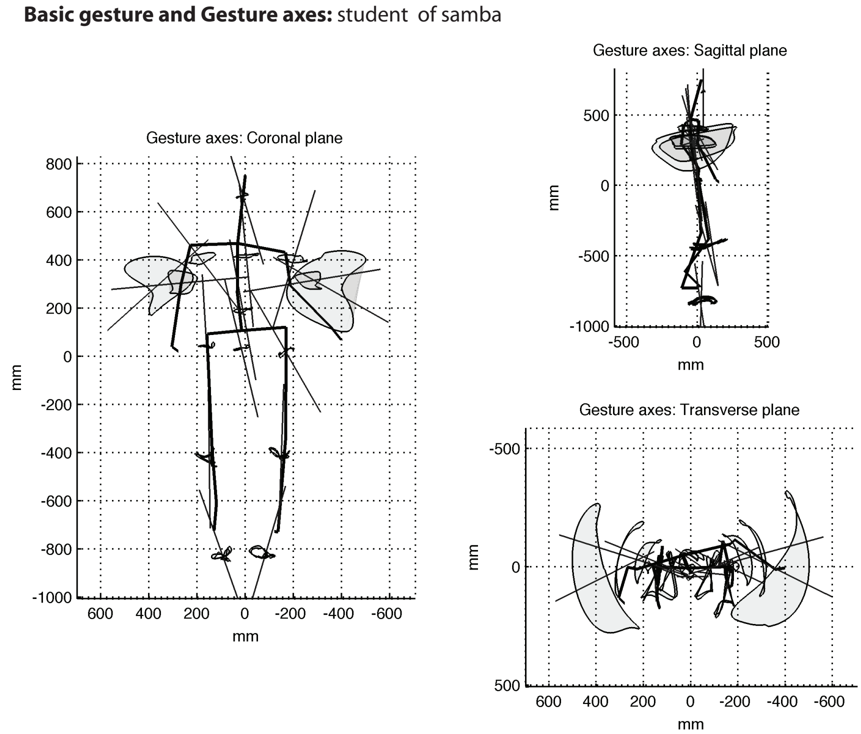

Figure 4.13: Stick figure and basic gesture of a samba dancer (student) with basic gestures and gesture axes for 16 joints.

signalized by sharp turns in the movement. In this case, metrical points may be more clearly entrained by other body parts. This shows that metrical steps are very important elements of dance behavior, especially in popular forms of dance.

4.3.4.2 Linking basic gestures with loudness

Basic gestures can be linked with different features, such as acoustic loudness and instantaneous velocity. These features can be relevant to the understanding of dance/ music relationships.

We developed a visualization based on the *tubeplot* scripts for Matlab from Sandberg (2009) that provides an example of how gesture trajectories offer a basis for crossmodal visualizations. In the example shown in Figure 4.15, the radius and the color shading of the transparent tube around the basic gesture are controlled by continuous variables, while the shape is defined by the basic gesture of the right hand (samba dancer). For visualization purposes in this example, the radius and color shading (in gray-scale) are controlled by the same variable. The idea behind

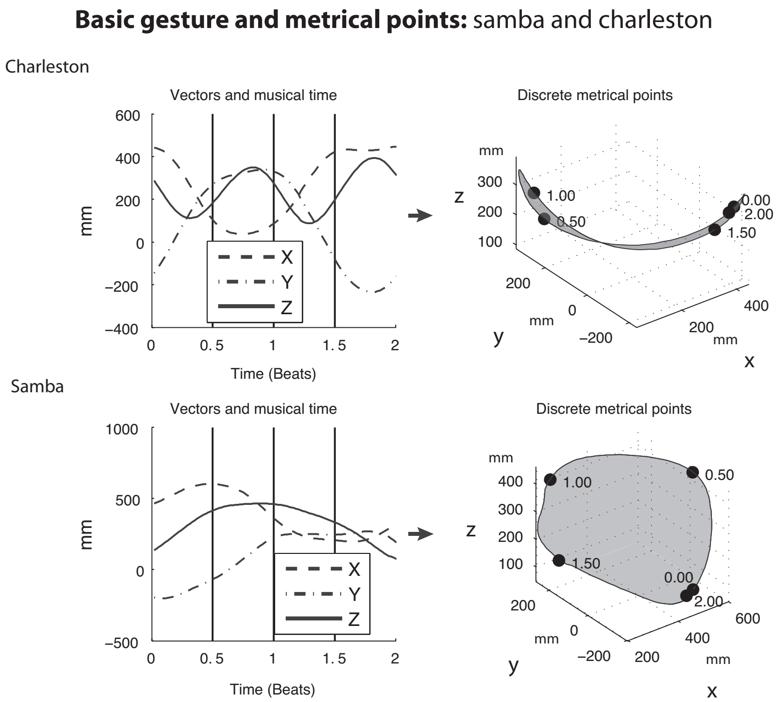

Figure 4.14: Linking basic gestures to musical time points. (a) The top panel displays the analysis of the right hand of the charleston dancer. The left part shows the musical time points in the horizontal axis, and the position of in each dimensional component x, y, and z in the vertical axis. The right part shows the reconstructed three-dimensional basic gesture with time points associated. (b) The bottom panel displays the same analysis, but for the right hand of the samba dance.

this visualization is to add visual cues (radius and color shading) for the observation of interactions between spatial description of gestures and other external variables. Obviously, the representation of external variables is explorative and symbolic, as these variables are not related to the physical space around the gesture. Note that the time represented here was previously transformed into a "periodic space" because the heuristics of the periodicity analysis projected the movement signals onto a periodic subspace. Therefore, continuous variables can only match this periodic time if they are an excerpt of the signal that fits the time of the periodicity (e.g., the first two beats of the signal), or if they are also periodicities, which were projected onto an identical periodic subspace (a subspace with the same period). In Figure 4.15, we projected the periodicity basis for loudness of the audio of the stimuli played during the experiment. We projected the loudness curves onto

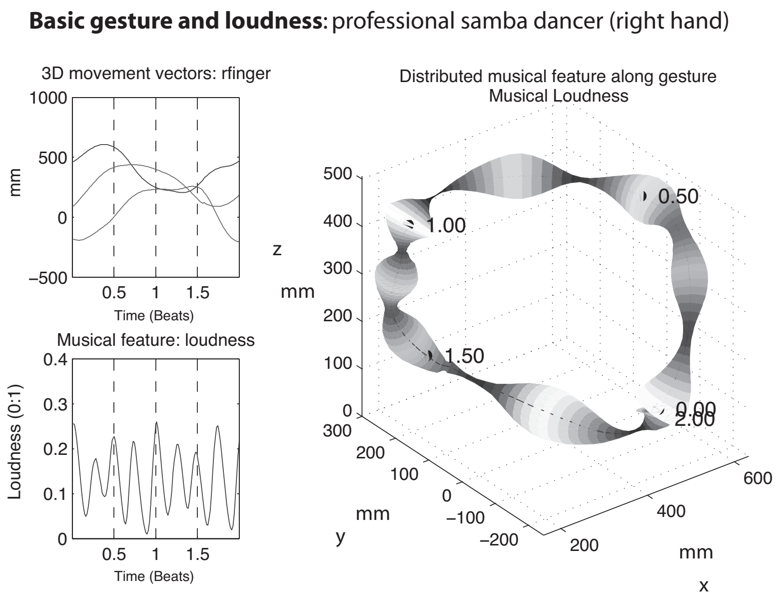

Figure 4.15: Tube plot of the basic gesture (samba dancer's right hand) with respective analysis of loudness patterns.

a subspace of two-beat period. The loudness curves were calculated using the IPEMtoolbox (Leman et al., 2001).

The periodicity of loudness patterns (continuous variable) controls the radius and color shading (black:white = 0:1) of the tube around the gesture path. The scale between the radius and the feature description must be defined manually because the connection between the physical quantities (e.g., radius in millimeters, loudness in ratio) in the representation is symbolic. The uses of logarithmic scales and other optimizations may be taken into consideration to improve the readability of the representation.

The representation produces the overall geometry of the gesture and introduces important information about the stimuli. For example, strong loudness onset periodicities seem to be placed at the time points where the gesture reaches the horizontal extremities of the spatial geometry.

These loudness onsets induce syncopation forces, while movement patterns seem to signalize metrical elements.

4.3.5 Linking basic gestures to kinematic features

In a similar way as with timing and loudness, it is possible to map kinematic features onto the basic gesture. Figure 4.16 displays the instantaneous speed derived from

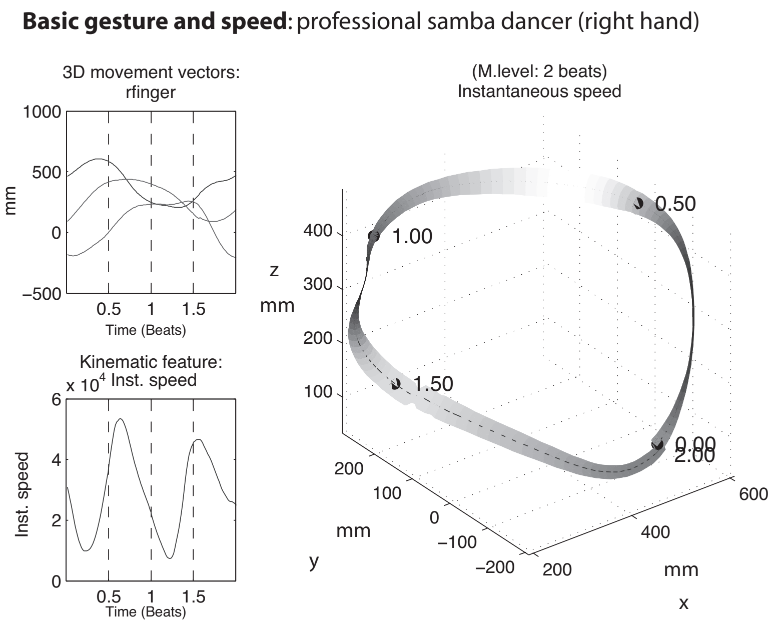

Figure 4.16: Dance gesture and representation of instantaneous speed.

the same periodic trajectories plotted against the gesture form. In this figure, we observe, on the one hand, that the speed of the gesture decreases as in the vicinity of the beat markers. Changes in speed require the use of more muscular energy to stop and reinitiate displacement. On the other hand, the lower speed observed in the beat points indicates a tendency to "rest" at the beat points. Note that when the first beat starts, the instantaneous speed grows more gradually, probably because of the gravitational force, which reduces the speed retake in the ascendant movement.

4.4 General discussion

The idea that basic gestures are spatiotemporal frames of reference for action-perception couplings can be related to studies that consider body-centered representations (though not necessarily from the viewpoint of dance/music couplings). Studies in phenomenology (e.g., Merleau-Ponty, 1945) and ecological perception (e.g., Gibson, 1979) were the first to draw attention to the fact that the cognition of space may be strongly dependent on the subject's action-oriented perception of the environment, suggesting that the representation of space is highly subjective and multifaceted. In this context, Previc (1998) distinguishes four major spaces, namely: (a) the *peripersonal space*, which is accessed by operations in the near-body space (similar to Laban's kinesphere); (b) the *focal extrapersonal space*, which is accessed through visual search and object recognition; (c) the *action-extrapersonal space*, which is accessed by orientation in a space containing referential landmarks or points; and (d) the *ambient-extrapersonal space*, which is characterized by orientation in an earth-fixed coordinate system. A related distinction can be made between *egocentric representations*, in which locations are represented with regards to the body-centered (eye-, head-, and arm-centered) reference frames, and *allocentric representations*, where reference frames for spatial localization are environment-centered, including those centered in an object of interest (Ghafouri & Lestienne, 2006). Additional characterizations are the *egocentric space*, or body space that is covered by our skin, or the back space or *no-motor space*, of which we are aware but cannot reach or see Saj & Vuilleumier (2007).

The study of peripersonal space is highly relevant to the problem of how dance and music are dealt with in terms of representations (Ghafouri & Lestienne, 2006). The concept of peripersonal space seems to imply a representation that depends on a body-centered orientation of the action (Ghafouri & Lestienne, 2006; Gourtzelidis et al., 2001). However, this representation would consist of multiple frames of body-centered reference (Caggiano et al., 2009), and arm length may constitute an intrinsic metric for the representation of near space (Longo & Lourenco, 2007). In that perspective, basic gestures for dance can be considered to result from multimodal integration of visual, vestibular, somatosensory, and auditory signals (Hidot et al., 2006; Lepelley et al., 2006; Longstaff, 2000), and the spatiotemporal reference frame can be considered from the viewpoint of spatial (body-centered) occupations (e.g., close or at a distance from the body-center). Although the studies on peripersonal space reveal different conceptions about the cognition of space, they all somehow rely on the idea that spatial cognition involves a subjective frame of reference that implies a body-centered viewpoint and an action-based orientation. The concept of basic gesture may be helpful in understanding the action-perception couplings of dance and music. However, further research will be needed to better understand and model the peripersonal representation in relation to the biomechanics of the human body, including rotation of the shoulders with respect to the body center. The present model of normalization may be limited to the kind of repetitive dance patterns that involve little rotation, such as the ones collected in the present study. In addition, further study is needed about the role of auditory cues in movement boosts. Styns et al. (2007) found that in walking on music, subjects walk faster on music than on metronome ticks at the same tempo. This suggests that several acoustical parameters, such as pitch, accent, loudness — which occur at specific points in time — may induce movement.

It is tempting to assume that spatiotemporal reference frames, which are based on auditory cues and eigenfrequencies of human body movement, may play a role as regulating mechanisms for the synchronization (tempo correspondence) and entrainment (phase correspondence) (Clayton et al., 2004) of action patterns in relation to music. It is furthermore important to note that the embodiment of music does not imply that the dancer would only mimic musical gestures through body gestures, as several authors have drawn attention to the fact that movement and gestures in samba contexts can be in counterpoint to the samba musical gestures (Browning, 1995; Sandroni, 2001; Sodré, 1979).

Although the present paper offers a method that extracts basic gestures from actually executed repetitive dance patterns, we believe that basic gestures can be conceived as frames of reference in the mental *and* motor domain, as was suggested in the introduction part of this paper (Brown et al., 2006; Farnell, 1994; Gallagher et al., 1998; Leman, 2007b; Metzinger, 2000; Sandroni, 2001; Tversky, 2003). Several authors have used the term *body schema* to denote a 'muscle memory' that guides the position of body parts with respect to one another over time, resulting in an internal dynamic model of the body (Buxbaum et al., 2000). In parallel, the term *body image* has been used to denote the conceptual knowledge about this guidance (Gallagher et al., 1998; Metzinger, 2000). Apart from the deployed basic gesture as a physically repetitive dance pattern, we believe that it is straightforward to conceive basic gestures as body schemata *and/or* body images that guide dance and music couplings in the motor and mental domain. This can also be linked to information theoretical and physiological studies of action perception couplings, where reference frames are assumed to play a role in guided action. For example, Lee (1998) has proposed a theory that deals with the description of the gap between a current movement state of a body part and a goal state. In this approach, basic gestures may function as spatiotemporal frames of reference for the guided motion and coupling of body parts (which can be mental-based or more motor-based).

In the threshold control theory (Feldman, 2009a; Feldman & Levin, 2009), a basic gesture could accomplish a reference frame that is defined by the sensory inputs to neurons, of which the reference threshold for minimal effort of movement can be modified in a feedforward way, in order to intentionally control the action. The theory takes into account the role of sensory modes in combination with representational modes (Paillard, 1991), which reflects the view that basic gestures provide frames for matching action and perception. In that perspective, a basic gesture is consistent with the idea of a memory for condition-specific thresholds shifts that handle reference frames that match action and perception. In that context, the reference to minimal effort takes on a significant importance in repetitive dances. We believe that dancers may obtain maximal rendition of gestures with minimal effort when the movements are close to the eigenfrequency of the body part. Further research is needed to conceive ways in which shifts from one gesture to the other gesture can be represented, as well as how the gestures can be nested into larger memory frames that make up entire choreographies.

4.5 Conclusion

The present study contributes to the idea that dancers perform music-driven repetitive dance patterns using spatiotemporal frames of reference, called basic gestures, that couple perceived musical cues with the movement of body parts. Technically speaking, these frames of reference can be conceived as spatial geometries onto which musical cues (and by extension also body cues) can be projected. Conceptually speaking, the spatiotemporal reference frames control minimum effort points in action-perception couplings. They reside as memory patterns in the mental and/or motor domains, ready to be dynamically transformed in dance movements.

The supporting evidence in favor of the concept of basic gesture is based on an approach where basic gestures are extracted from repetitive dance patterns. This approach is based on several assumptions that define and confine the concept of basic gesture; such as the idea of a body-centered frame of reference, embodiment of musical cues in dance gestures, minimal effort in relation to spherical spaces and resonance frequencies, the direction of the so-called gesture axis, and so on. It cannot be denied that, given these assumptions, and given the limited amount of subjects that have been observed so far, the proposed concept of basic gesture is still in an early stage, and that more work is needed that should contribute to a refinement of the concept.

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5

The Spatiotemporal Representation of Dance and Music Gestures using Topological Gesture Analysis (TGA)

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Abstract

Spatiotemporal gestures in music and dance have been approached using both qualitative and quantitative research methods. Applying quantitative methods has offered new perspectives but imposed several constraints such as artificial metric systems, weak links with qualitative information, and incomplete accounts of variability. In this study, we tackle these problems using concepts from topology to analyze gestural relationships in space. The Topological Gesture Analysis (TGA) relies on the projection of musical cues onto gesture trajectories, which generates point clouds in a three-dimensional space. Point clouds can be interpreted as topologies equipped with musical qualities, which gives us an idea about the relationships between gesture, space, and music. Using this method, we investigate the relationships between

musical meter, dance style, and expertise in two popular dances (samba and Charleston). The results show how musical meter is encoded in the dancer's space and how relevant information about styles and expertise can be revealed by means of simple topological relationships.

5.1 Introduction

The idea that dance and music are closely coupled is supported by studies on cultural aspects of dance (e.g., Grau, 1983; Jordan, 1993, 1994) and music (e.g., Becking, 1928; Gritten & King, 2006; Schneider et al., 2010) that include anthropology (e.g., Blacking, 1983; Desmond, 1994; Hanna et al., 1979) and ethnography (Browning, 1995; Grau, 1983; Hoerburger, 1960). Studies on dance cognition (Stevens & McKechnie, 2000), synchronization (Goebl & Palmer, 2009; Repp, 2005, 2006), spontaneous dancing to music (De Bruyn et al., 2009; Toiviainen et al., 2010), and musical gesture research (Godøy & Leman, 2010) have given us further insight into the fact that this coupling implies the occurrence of spatiotemporal cues that relate positions of body parts to musical events.

The availability of quantitative research methods for the recording and analysis of body movement has opened new perspectives for cultural studies on dance (Desmond, 1994, 2000). Examples include methods based on video analysis (Camurri et al., 2004; Guedes, 2006; Jensenius, 2006), motion capture data (Dahl, 2000; Palazzi et al., 2009; Shiratori et al., 2003; Wanderley et al., 2005b) and sensing devices (e.g., Clynes, 1995; Enke et al., 2006; Yamamoto & Fujinami, 2008). However, the recording techniques impose several constraints. The type of metrics imposed by recording systems (Carlsson, 2009), the high amount of movement variability (Stergiou, 2004), the role of context factors, and the typical separation of the dance phenomena into music and movement modalities (Camurri et al., 2006; Naveda & Leman, 2009) all present challenges. In this study, we propose methods that deal with some of these problems using concepts from topology. The method is illustrated by a case study on samba and Charleston dances.

In this paper, we propose to use concepts of topology in the analysis of musical gestures. By considering dances as music-driven action-oriented explorations of spatial regions, we study two dance forms using a novel method, the Topological Gesture Analysis (TGA). The TGA method consists of two main parts. In the first part, musical metrical cues are projected onto the space of dance gestures. Rather than looking at the basic shape of the gesture, we use this projection on a sequence of repeated dance gestures, which results in point clouds of musical cues distributed in space. The structure of the point clouds can be further clarified with simple multivariate techniques. In the second part, the qualitative relationships of connection, envelopment, proximity, and variability of these point clouds are studied in relation to the dancers' bodies. These point clouds are represented as geometrical abstractions that can be linked to each other, as well as to peripersonal space of performer (i.e., the space surrounding our body that can be reached by our limbs). This methodology borrows from methods used in point-set topology, which helps to identify point cloud topologies. The methodology also borrows from qualitative topology and region-based approaches that help to interpret and classify it and helps connect qualitative knowledge to point cloud topologies (for an overview of these processes see Carlsson, 2009).

5.1.1 Background in spatiotemporal dance analysis

The TGA method is complementary to the basic gesture approach that was introduced in Naveda & Leman (2009), and further elaborated upon in Leman & Naveda (2010). To summarize, basic gestures are spatiotemporal shapes of movement trajectories of body parts that function as frames of reference for the guidance of the coupling of dance and music. They can be extracted from a repetitive dance pattern and represented by geometrical shapes onto which musical cues are projected. For example, Figure 5.1 shows the basic gestures of the right hand in a samba dance (samba-no-pé sub style), as performed by a male and a female in three different tempi (57.5, 73.3, and 89.2 bpm). The period of the repetitive gesture is two beats and the points and numbers represent the spatial deployment of these gestures at each half beat step (see also Leman, 2007b; Leman & Naveda, 2010; Naveda & Leman, 2009).

Notice that the shapes of the basic hand gestures of the male and female samba dancer are different. The male dancer displays a diagonal and oval shape (related to the elbow joint), while the female dancer displays a fixed pendulum-like shape (related to the joint of the shoulder). The diversity of shapes relate to known and unknown sources of variability that are intrinsically linked to human movement behavior (Stergiou, 2004). These differences may pertain to the dancer's diverse, but specific, gestural repertoire of basic gestures used in the dance style. In order to grasp the invariant properties that make the dance style recognizable and reproducible, it would be interesting to perform a complementary analysis that focuses more on finding simpler properties of repetitive dance patterns in relation to the surrounding space and the musical cues. For example, consider the interaction between metrical points (half beat steps) and how they are organized with respect to the dancer's body in Figure 5.1. First, these points can be located in regions of the space that are sensitive to the body reference, namely places that are close to the torso and the places at the extremity that they reach with their hands. Although the starting beat position of these gestures (position 0) can be inverted (e.g., excerpt 1 would start close to the body), they oscillate between these two regions, or "references" in respect to the dancer's body. The points 0 and 2 are always at the extremity of the cycle and the opposite extremity is always placed between the points 1 and 1.5.

In short, the basic gesture approach can be complemented by an approach that considers the dancer's surrounding space as regions that are equipped with qualities (regions that mirror qualities of musical meter and body references) that exhibit simple invariant properties with respect to each other. An approach that is more sensitive to the quality and the relationships of information leads to the concept of topology (Carlsson, 2009, p. 256).

5.1.2 Qualitative analysis of music-driven dance patterns

Topology — the study of topos, "place" — deals with qualitative geometric information (Carlsson, 2009; Kinsey & Moore, 2001) such as proximity, connectivity, and envelopment, ignoring information about shape, distances, sizes, and angles. This highly general idea of geometry differs from other concepts of geometry by the range of transformations that it permits (Rosen, 2006): While in Euclidean and projective geometry objects that are similar must preserve precise distances and/or coordinates, two objects are topologically equal if they can be continuously deformed into one another. Historically, this flexibility has provided a tool for mathematical abstraction, in which one can infer inherent connectivity of objects while ignoring their detailed form (Weisstein, 2010). More recently, it has offered a more embodied perspective on geometry by inspiring studies in the field of philosophy (i.e., "topology ... is rooted in the body" Sheets-Johnstone, 1981, p.42), and phenomenology (e.g., Merleau-Ponty et al., 1968). However, many modern applications of topology combine quantitative information (such as points measured in space, distances, angles) or more or less abstract quantities to derive topological relationships. Examples of these applications can be found in fields such as qualitative reasoning (e.g., Cohn et al., 1997), geographical information systems (GIS, e.g., Bogaert et al., 2004), and spatial cognition (e.g., Freksa, 1991; Knauff et al., 1995).

The structure of the paper is as follows: In the Method section, we describe the apparatus used in the recordings and give a detailed account of the principles of the TGA method and procedures used by the subjects and in dance performances. In the Results section, we analyze samba and Charleston styles, focusing on the gestures of the hand and feet. This section is complemented with the results of the analysis of the hand gestures at different levels of expertise in samba style. In the Discussion section, we use concepts of general topology to establish relationships between gestures, the dancer's body, and musical structure. We devote special attention to the metrical properties embodied in the dance forms.

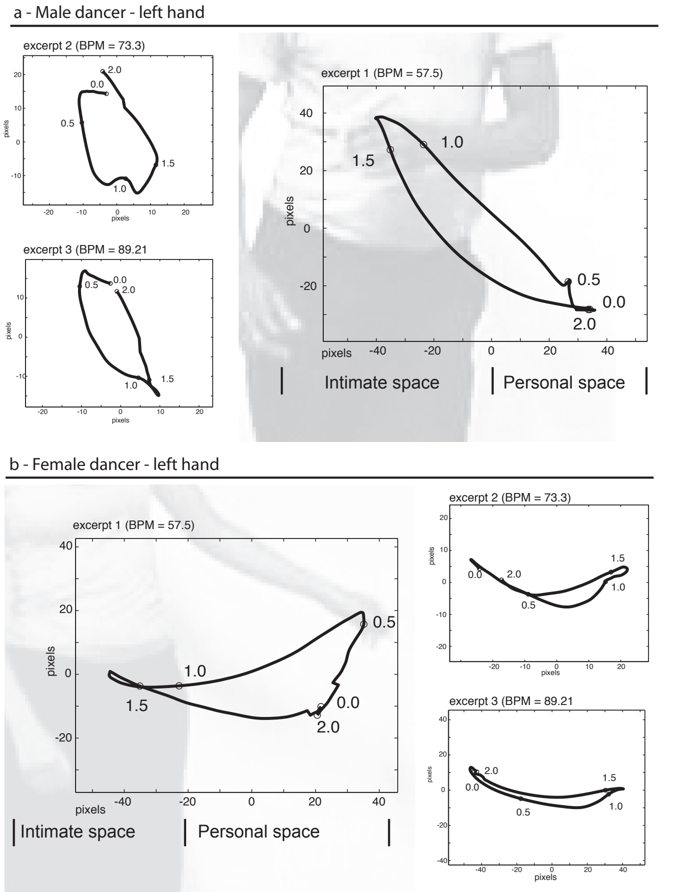

Figure 5.1: Basic gestures of the right hand for two dancers (male and female) in three different tempi (see figure). The basic gestures of the male dancer have a diagonal/vertical characteristic, while the basic gestures of the female have a horizontal characteristic. Intimate space refers to the space occupied by the dancer's body, personal space refers to the space within the reach of the dancer's body (Hall, 1968). Time positions refer to the beat durations (e.g., position 0 means the beginning of the first beat) as displayed in (Naveda & Leman, 2009, p. 269).

5.2 Method

5.2.1 Apparatus

The TGA method described below is here applied to data from a motion capture system (Optitrack/Natural Point) that consisted of 12 cameras positioned around a squared aluminum structure (6 x 6 meters) and a computer workstation. Each session was 60 s in length and was recorded at a frame rate of 60 Hz, interpolated to 100 Hz in the editing phase. The motion capture recordings were synchronized with audio in the editing phase, using movement cues (claps) performed in synchrony with audio (predefined onsets) before the music stimulus. The recording sessions were edited and exported as C3D files using ARENA software (Natural Point). The sequences were imported into Matlab by using the MoCap toolbox (Toiviainen & Burger, 2010). The calculation of body basic joint positions, filtering of raw vectors, normalization and part of the visualization functions were also based on the MoCap toolbox.

5.2.2 Normalization of trajectories

Infrared motion capture systems produce raw data that indicates the position of the reflective marker in a Cartesian three-dimensional space. This means that not only the dimensions of the system are defined in relation to fixed points (e.g., a fixed point in the floor), but also that they remain fixed even if a dancer changes the whole-body position or orientation during the performance. The description of the whole body in the space represents a relevant gestural content. However, during this experiment, we limit our observations to the movement performed by dancers with respect to their own bodies. Therefore, the trajectories in free space are normalized with respect to one reference point and orientation of the dancer's body (the point is defined as the centroid of the body across markers and the orientation as a frontal view with respect to the left and right hips). This procedure subtracts the influence of whole-body rotation and translation from the raw trajectories.

5.2.3 Application of the method

The TGA method includes four distinct phases, namely (1) definition of musical cues, (2) the projection of the cues onto trajectories, (3) discrimination and measures of dispersion, and (4) analysis of point cloud relationships.

5.2.3.1 Definition of musical cues

Musical cues can be assigned to different categories and levels (Lesaffre, 2005). In an attempt to formalize temporal relationships in music (and dance) in terms of metrical levels, we adapted the syncopation model of Longuet-Higgins & Lee

(1984) to two beats. The reason for this extension to two beats is that in samba and Charleston, levels of syncopation would typically be organized every two beats (or even every four beats in case of Charleston). The extended model is shown in Figure 5.2.

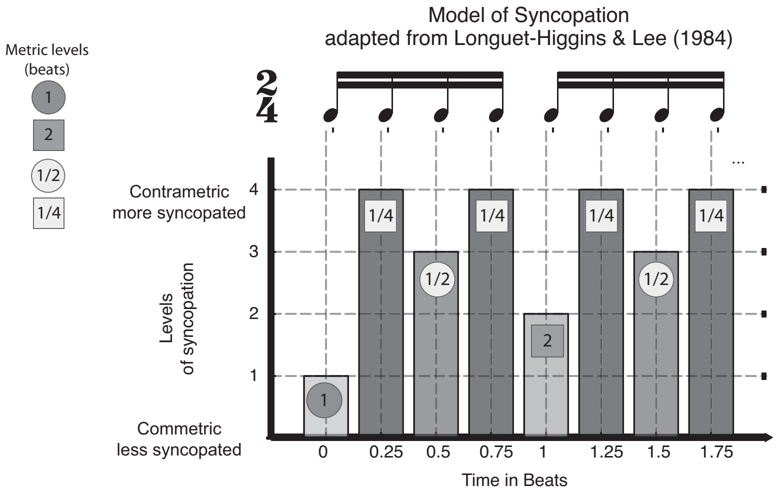

Figure 5.2: Model of syncopation applied to samba and Charleston (adapted from Longuet-Higgins & Lee, 1984). The sequence of levels 1, 1/4, 1/2, 1/4, 2, 1/4, 1/2, 1/4 represent the metrical levels, or categories of syncopation, ranging from commetric to contrametric.

This metrical model is closely related to the concept of syncopation, which is especially important in the context of pan-African music (Browning, 1995; Chernoff, 1991; Sodré, 1979). Henceforth, the non-syncopated or metrical elements are called *commetric*, and the more syncopated/non-metrical elements are called *contrametric* (following Kolinski, 1973). In the model shown in Figure 5.4, the first beat and second beat positions (1- and 2-beat levels) are less syncopated, and therefore more *commetric*, than the other elements. The other positions display elements with more syncopation, or more *contrametric* (1/2- and 1/4-beat levels).

In the subsequent analysis of musical excerpts, the time position of the beats (1- and 2-beat levels) are obtained by manual annotation. The time position of the tatum points (1/4 of the beat) are obtained by subdividing the beat durations. Hereafter, the metrical levels described by this model will be referred as 1-, 2-, 1/2-, and 1/4-beat levels.

5.2.3.2 Projection of musical cues onto trajectories

The metrical cues can be marked on the gesture trajectory of the joints of the dancer's body, as shown in Figure 5.6. This leads to the emergence of point clouds that are qualitatively connected with the metric levels in space. In other words, we assume that these points borrow the metrical quality projected in space from the quality of the musical cue. If the dancer elaborates the gestures in space according to one of the metrical cues, the subsequent projections of features will bring about an accumulation of point clouds within a region in space. The cues will tend to converge to clusters that will display different forms and distributions in space (spheres, ellipsoids, etc.). Figure 5.3 shows the emergence of clusters in six time instants.

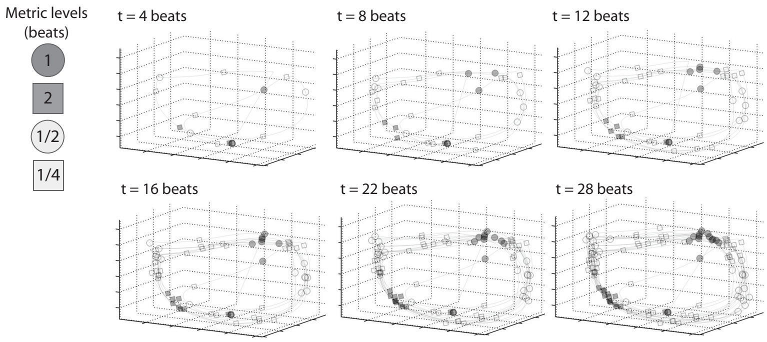

Figure 5.3: Evolution of the projection of musical cues in space. The sequence of graphs demonstrates the accumulation of cues in point clouds. Different point markers denote different metrical levels. Note that some clusters are more convergent and others are more dispersed.

5.2.3.3 Discrimination, outliers and measures of dispersion

The point clouds can be separated from each other by implementing multivariate techniques such as linear discriminant analysis (LDA), quadratic discriminant analysis, or clustering techniques such as k-means or agglomerative clustering. The main reason for the use of this procedure is to distinguish between the point clouds by means of clear boundaries. In this study, we used the linear discriminant analysis (LDA) to recognize which points could be discriminated from a linear combination of spatial features in the three-dimensional space (see Carlsson, 2009, for an overview of these processes in point cloud topology). Figure 5.4a displays the point clouds without any discrimination process. Figure 5.4b displays the result of the LDA analysis. Figure 5.4c displays the result of the analysis (circles and squares) and the points that were not correctly predicted by LDA (filled triangles).

In this study, we assume that correctly predicted points after LDA offer a feasible separation between categories. Incorrectly predicted points are excluded from the set of points (see Morrison, 1969, for an overview of the LDA).

In this experiment, outliers seem to emerge from erratic gestures, improvisation, or movements that were not part of the proposed task. Further analysis showed that most of the outliers could be detected by excluding points that are above or below two times the interquartile range of the distribution in each category, in any dimension. Point cloud topologies with less than three points also were excluded from the point cloud representation and abstractions. These processes were implemented after the linear discriminant classification (LDA) was applied.

In what follows, we use two additional measures for the point cloud topologies, namely, *recognition rate* and *generalized variance*. The *recognition rate* (hereafter *rr*) is the rate between correctly predicted and incorrectly predicted (including outliers). It is intuitively linked to the quality and strength of the link between musical cue and point cloud in space. The *generalized variance* (Wilks & Olkin, 1960; Wilks, 1932) indicates the dispersion of the point clouds and indicates if this relation with space is compact or loose. The *generalized variance* is calculated as the determinant of the covariance matrix of the positions for the points of the point cloud region (Wilks & Olkin, 1960, p. 487). In order to provide a better scale of comparison between measures of dispersion, we used the cubic root of the *generalized variance* in the graphical representations. Figure 5.5 shows an example of three different point clouds and the relationship between the dispersion and density of points in space by means of generalized variance and *recognition ratio*.

5.2.3.4 Analysis of topological relationships

Relationships of connectivity, envelopment, and proximity between point-clouds can be analyzed with respect to (1) each point-cloud, and (2) the peripersonal space. The topologies can be represented by abstractions, represented by simple geometric forms (e.g., spheres, ellipses) that can be linked with the concept of basic gestures. These are frames of reference of which the size will roughly represent the relative measures of dispersion and position in relation to peripersonal space (see Ghafouri & Lestienne, 2006; Hall, 1968; Previc, 1998). The peripersonal space can be represented by references to the human body (e.g., stick figure), by considering subclasses of the peripersonal space (e.g., intimate space, personal space), the orientation of the interactions (orientation of the body figure in the ambient-extrapersonal space, which is the space beyond the reach of the dancer's limbs), and the direction of gestural movement (arrows). In this study, representations of the *intimate* and *personal space* are used as points of reference that help to interpret the interactions of topologies within the peripersonal space. The notion of proximity/distance of intimate and personal spaces also conveys biomechanical and physical limits and

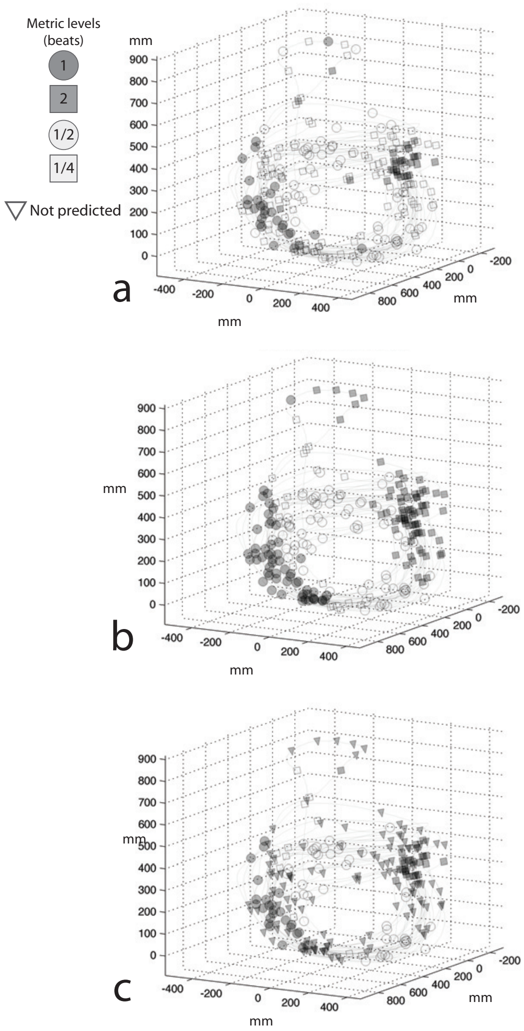

Figure 5.4: (a-c) Process of exclusion of points that were not predicted by LDA (example extracted from right hand, samba). See the legend for the identification of categories. The three phases display the (a) original point cloud categories, (b) point set categories after LDA, and (c) correctly predicted and incorrectly predicted point cloud categories.

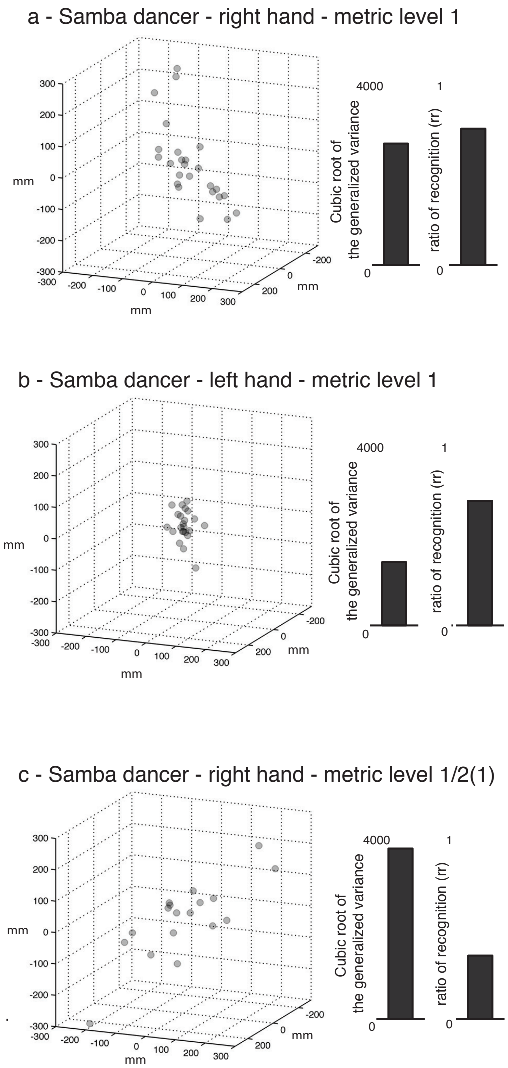

Figure 5.5: (a-c) Three examples of point clouds extracted from the hands of the samba dancer. In Figure 5.5a, the metrical level 1-beat is projected onto a dispersed point cloud, which has a high ratio of recognition. In Figure 5.5b, the point cloud is compact and has a high ratio of recognition. In Figure 5.5c, the point cloud is dispersed but represents very few points that were correctly recognized after LDA was applied and the outliers were excluded. The points are represented by markers with a diameter of approximately 20 mm.

other symbolic, social and choreographical references, which will not be discussed in this study. See Figure 5.6 for an example of abstraction derived from the point cloud data in Figure 5.4.

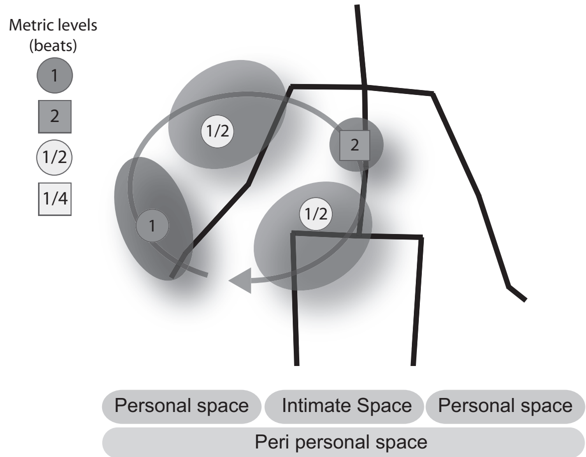

Figure 5.6: Example of abstractions derived from the point cloud data and representation of the peripersonal space (stick figure and peripersonal space boundaries). These high-level abstractions, or topologies, are based on the data displayed in Figure 5.4. They convey a more qualitative representation of the relations between meter and dance gestures in space.

5.2.4 Procedure

In what follows, the TGA method is applied to excerpts of samba and Charleston dance. Attention is particularly devoted to the dance style (the distinction between samba and Charleston) and to the level of expertise (the distinction between expert and novice).

Two professional dancers and two dance students participated in the experiments (all females). The recordings of the two professional dancers were used in the analysis of samba and Charleston styles. The Charleston dancer was a female Dutch dancer/teacher of old and traditional dances who had several years of experience in performance and teaching. She performed dances in basic Charleston style. The second professional dancer was a Brazilian female dancer/teacher of Afro-Brazilian dances who had several years of dance experience in performance and teaching. She performed dances in "samba-no-pé" style, the main substyle of the samba dances. After a few trial runs without any imposed limitation, the dancers were instructed to dance the standard steps that are typical for the samba-no-pé and

Charleston styles, without exhibiting improvisations, turns, or embellishments. All the participants were recorded during different sessions in a closed environment (without the presence of observers).

To analyze the level of expertise, we compared the hand movements of the same professional samba dancer with those of two of her students. The two students were Belgian, with one and a half years of dance experience. They were enrolled in dance lessons with the same dancer who participated as a professional samba dancer.

All dancers were asked to perform several instances of the basic dance forms within a limited circular area (diameter = 4 m), in a relatively isolated environment. They wore a dance suit with 34 reflective markers attached to it, which provided the point-set representation of the body morphology. The markers were placed on: head (3), upper arms (3 + 3), upper back (3), hips (4), hands (3 + 3), thighs/knee (2 + 2), shins (1 + 1), and feet (3 + 3). The stimuli used to perform the samba dances (professional dancer and students) were composed of looped samples of a samba percussion ensemble (*surdo*, *tamborim*, and *caxixi*), recorded in Brazil, using a multitrack recorder. The stimuli used in the Charleston recordings were composed of phrases of Charleston music ("Novelty Charleston," Titanic Ensemble). The mean bpm for the stimulus sequences were 90 bpm for samba and 111 bpm for Charleston.

5.3 Results

5.3.1 Style in dance: analysis of hand movements

5.3.1.1 Applying the syncopation model

In order to provide a neat visualization of the methods, only the movements of hands and feet were taken into account during the analysis of style. Figure 5.7 shows the point clouds of Charleston and samba gestures (hand). Points represented by different markers (see legend) indicate projections of the different metrical cues (1-beat, 2-beat, 1/2-beat and 1/4-beat) onto the trajectories. They arise from the main repetitive gesture that is part of the repertoire of the dance styles. The regions are outlined using LDA.

Figure 5.8a shows the abstractions of the point clouds observed in Figure 5.7 for the hands in samba. First, if we consider the direction and phase of the movement of the two hands, we see that they face in opposite direction of each other and all this occurs with a shift in phase (one beat of phase delay, if considered in relation with to the dancer body). During the first beat, the area close to the chest is occupied by the left hand, and by the right hand during the second beat. The whole pattern repeats itself every two beat periods. Second, we considered the position of the hands with respect to the body-center. The circular movement of the hand

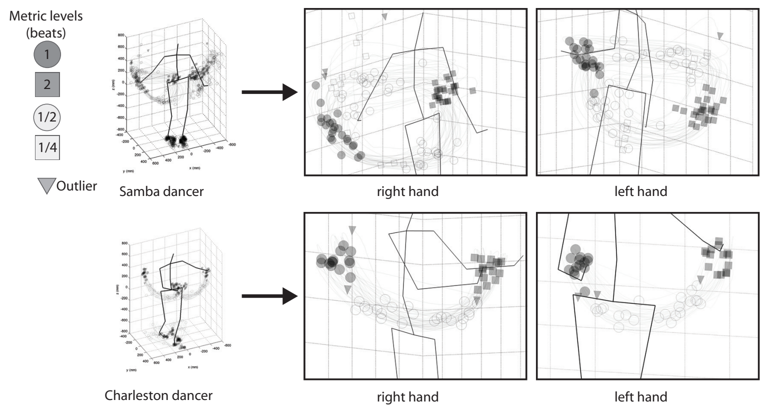

Figure 5.7: (a-b) Hand gestures and point clouds in samba and Charleston dance forms. The axes on the 3D representations represent distances in mm. The points are represented by markers with a diameter of approximately 20 mm.

proceeds from the intimate space (close to the dancer's body) to the boundary of the peripersonal space (away from the dancer's body). For each cycle of two beat periods, the boundary of the peripersonal space is determined by complementary metrical topologies, namely, the 2-beat level for the left hand and 1-beat level for the right hand. Abstractions for the metrical level 1/4-beat are not displayed because this level was poorly predicted by the LDA analysis and most of the points were considered as outliers (see Figure 5.8b and further discussion). Note that this figure confirms the same pattern of observations as in Naveda & Leman (2009), illustrated in Figure 5.1.

Next, we looked at the dispersion of the point clouds for each metric category in Figure 5.8b. It suggests that for the left and right hand, the regions where the 1-beat level and the 2-beat level occur, are less dispersed than the regions where the 1/2-beat and the 1/4-beat occur. In case of the right hand, the space occupied by the 1-beat level seems to be slightly more spread over the bottom/left extremity of the gesture and slightly more linearly predictable (rr = .79) than the left hand (rr = .72). The indication of one single topology for the metrical levels 1 and 2 is quite pertinent here. Since there is only one position for metrical levels 1- and 2-beat in the syncopation model (Figure 5.2), the existence of one single point cloud for a given level indicates that the dancer uses the same space to represent a unique category of the musical cue. However, the existence of two or more point clouds for one metrical level would indicate that the dancer uses more than one region of space in synchrony with a single metrical level. In this case, the adapted Longuet-Higgins model is not suitable or the dancer is using different choreographies at different times during the dance sequence.

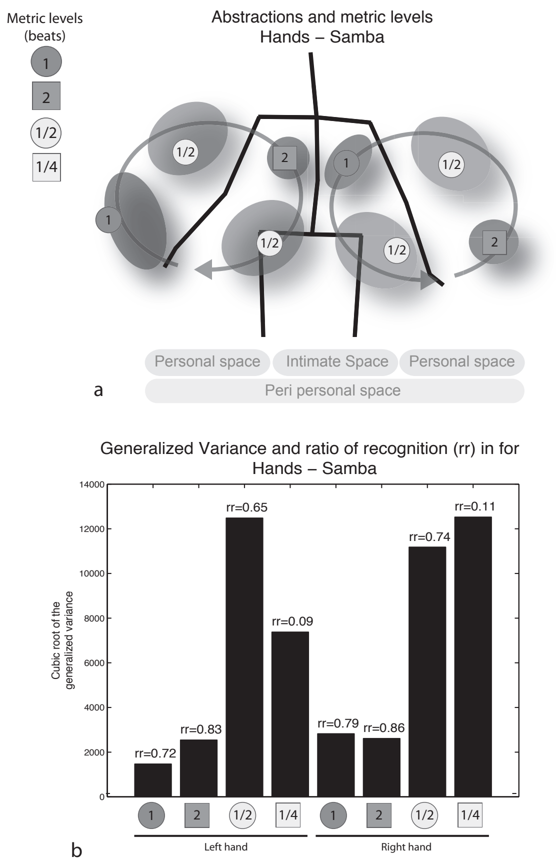

Figure 5.8: (a-b) Topologies and measures of dispersion for the hand, samba dancer. (a) Stick figure of the dancer and abstractions of the meter-based topologies for the hands in samba dance. (b) Measures of dispersion: generalized variance and ratio of recognition.

5.3.1.2 Applying the adapted syncopation model

According to the information shown in Figure 5.8b, the dispersion of the 1/2-beat level is much larger than other metrical levels (which is clearly the case in both hands). However, Figure 5.7a, and its abstraction in Figure 5.8a, suggest that this 1/2-beat level actually is represented by two distinct point clouds. Hence, the validity of the dispersion measure, which was based on the model by Longuet-Higgins & Lee (1984) for the entire 1/2-beat level (and by extension also the 1/4-beat), should be refined by considering sub-categories. Therefore, we conducted a new LDA analysis on subcategories of these metrical levels, which are called 1/2(1) beat and 1/2(2) beat. We also consider four sublevels for the metrical level quarter-beat, referred as 1/4(1) to 1/4(4). The use of this procedure is illustrated by Figure 5.9a-d. First, the points predicted in the first LDA analysis are isolated (Figure 5.9b). Then, we classified these points using an extension of the original categories attached to the sublevels: 1/2(1) and 1/2(2) (Figure 5.9c). The result is a set of two main metrical categories (1-beat and 2-beat), and six metrical subcategories (two categories for the 1/2-beat and four categories for the metrical level 1/4-beat). Figure 5.9d displays the resulted abstractions of the sublevels 1/2(1) and 1/2(2).

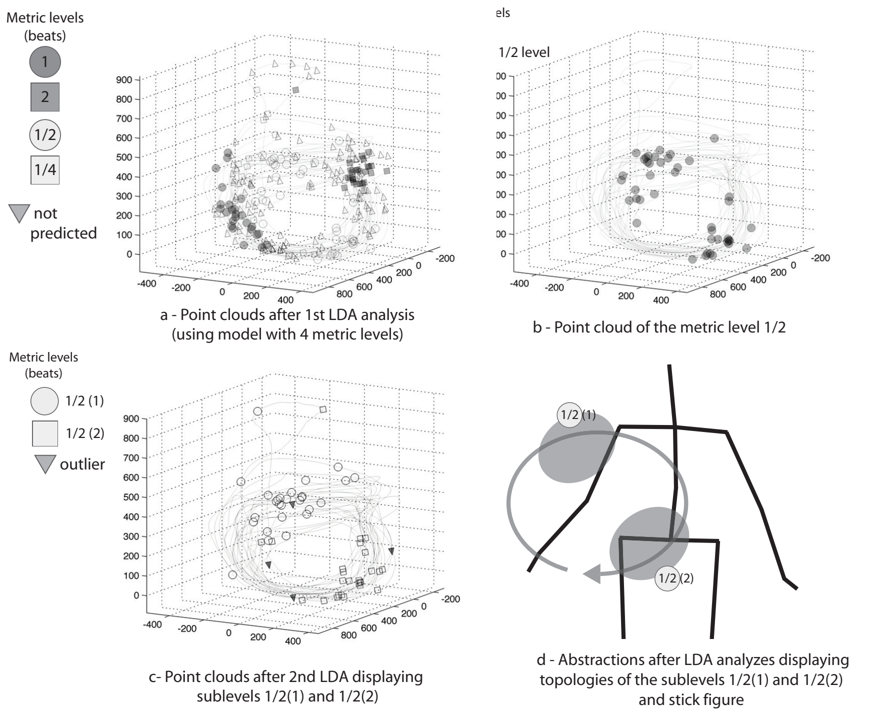

Figure 5.9: (a-d). Calculation of the LDA for the sublevels of the model of syncopation. Figures 9a and 9b demonstrate how the points predicted by LDA with the original syncopation model are isolated. Figure 5.9c demonstrates the result of the LDA for the sublevels and Figure 5.9d shows the abstractions that represent the topologies in 9c. The axes on the 3D representations represent distance in millimeters. The points are represented by markers with a diameter of approximately 20 mm.

Finally, Figure 5.10 demonstrates the calculations of the dispersion using the improved model of syncopation. We consider that the dispersion and prediction for points have changed due to the subsequent LDA process at sublevels.

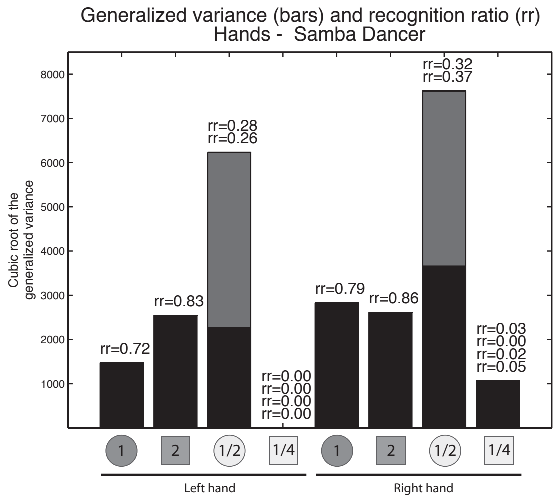

Figure 5.10: Results of the dispersion measure of the hands in samba, using the improved syncopation model. The subsequent processes of LDA and exclusion of outliers resulted in very low ratios of recognition (*rr*) for 1/4-beat points. The different colors in the bars represent the contribution of a single sublevel to the overall dispersion.

5.3.1.3 Meter-related topologies of Charleston hand gestures

Figure 5.11a shows the abstraction of topologies of the hands in Charleston. Differently from samba, the two hands move in the same direction, in the same phase and in the coronal plane (note that the organization of topologies of the hands in Charleston seem identical to each other). With respect to the position to the body-center, the arms move more like a pendulum, and the boundaries of the peripersonal space are synchronized with the first and second beat of the music. Observe that the 1- and 2-beat levels are situated on the upper part of the gesture while the 1/2-beat levels are situated at the lower part of the overall gesture.

Figure 5.11b shows that the 1- and 2-beat levels are less dispersed and strongly discriminated agaist each other by the use of LDA. Sub-levels of the -beat level are only marginally predictable but they are as dispersed as 1- and 2-beat levels. However, the sum of the sublevels and its superposition in the same region provokes a dispersed 1/2-beat region situated in the lower part of the gesture. As seen in Figure 5.7, the 1/4-beat levels were excluded by subsequent processes of discrimination.

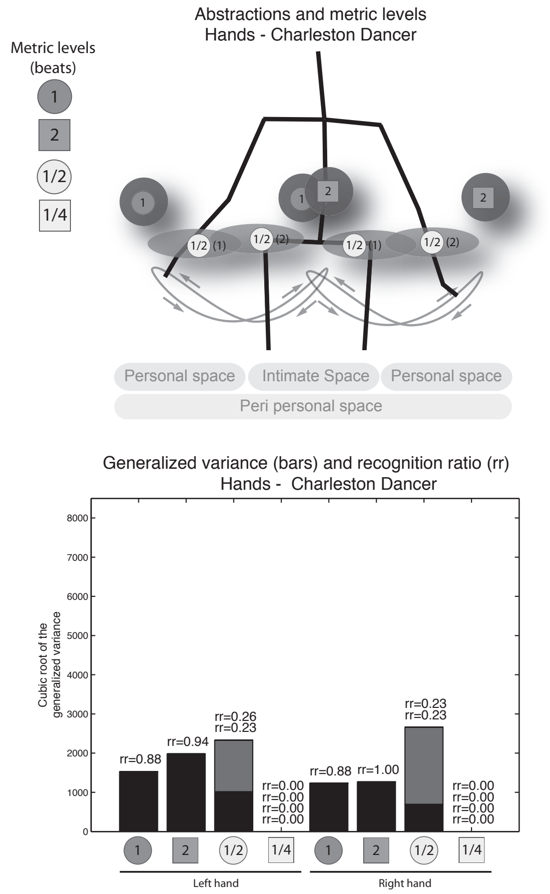

Figure 5.11: (a-b) Topologies and measures of dispersion for the hand in Charleston (see point clouds in Figure 5.7). Figure 5.11a shows the stick figure of the dancer and abstractions of the meter-based topologies for the hands in samba dance. Figure 5.11b displays the measures of dispersion.

5.3.1.4 Comparison of topologies of samba and Charleston hand gestures

Compared to samba, 1- and 2-beat regions are more compacted and spatially discriminated in Charleston. Conversely, the 1/2-beat regions of the hands in Charleston show less clear discrimination and less dispersion than in samba. The 1- and 2-beat regions found in front of the chest overlap with each other in space (but not in time). If one looks at the shape of the repetitive movements (such as Leman & Naveda, 2010), the "pendulum-like" gesture in Charleston seems to have a different origin than the one in samba, which exhibits a circular interaction at metrical levels.

However, from a topological viewpoint, these two forms are invariant, or more precisely *homeomorphic*. Figure 5.12 demonstrates that as a result of a continuous deformation of the shape of the gesture in samba, the same shape of the hand gesture in Charleston exists. This observation suggests that, at this level of topological abstraction, the gesture preserve the same mappings between categories of space after continuous deformations (Prasolov, 1995).

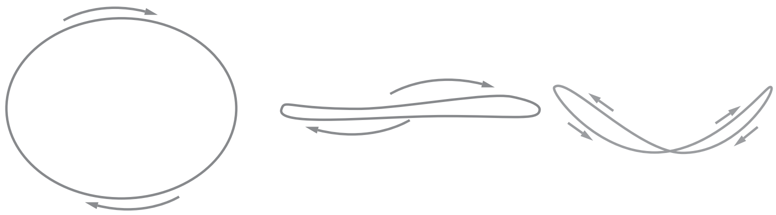

Figure 5.12: In topology, transformations of the shape do not affect the interactions between topological spaces. This example demonstrates how the first geometry that represents the interactions between regions in samba dance can be transformed into the third geometry that represents the “pendulum” aspect of the topology in Charleston gestures. The concept of shape loses its importance in favor of interactions between qualitative information in space.

5.3.2 Analysis of foot movements

5.3.2.1 Meter-related topologies of samba feet gestures

The distributions of point clouds for the feet are more complex than for the hands, with respect to the interpretation and discrimination of categories. Figure 5.13 demonstrates how these point clouds are compacted and interleaved. The point clouds also reveal less symmetry and how several metrical levels overlap with tiny regions in space.

Figure 5.14 shows the abstractions that indicate the relationships shown in Figure 5.13. The organization of topologies suggests that the spatiotemporal structures of the right foot and left foot are similar: the 1-beat level is positioned on the left side, the 2-beat on the right side, and the 1/2-beat region is positioned in front of both feet. In contrast to other body parts, a distinct 1/4-beat region covers the space in front of the feet. The ratio of recognition of points indicates a similar pattern existing in all dances and body parts: commetric levels (1-and 2-beat) are highly predicted while contrametric levels (1/2- and 1/4-beat) are not.

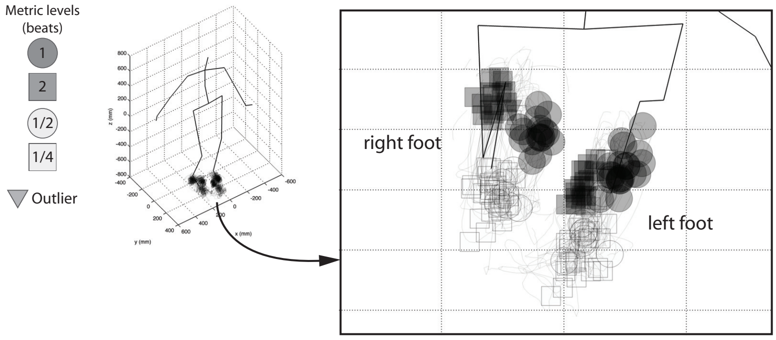

Figure 5.13: Detail of point cloud topologies of the feet, in samba style. The axes on the 3D representations represent distance in millimeters. The points are represented by markers with a diameter of approximately 20 mm.

5.3.2.2 Meter-related topologies of Charleston feet gestures

Figure 5.15 shows the point clouds of the feet for the Charleston dance. The data suggest that the projection of the right foot is made in front of the intimate space and the left foot is projected behind the center of the intimate space, so as a result 1-beat regions can be found at the extremities of the peripersonal space (see representation of the peripersonal space in Figure 5.16). Concurrent 1- and 2-beat topologies are situated within the boundaries of the intimate space. We observed the same problem during the application process of the 1/2 and 1/4-beat sublevels. However, the existence of alternative regions at the 1-beat level suggests that during part of the movements cycles, the 1-beat level is synchronized with one region in space, while during other cycles, it is synchronized with another region. Two hypotheses can be made to explain this: (1) the movement is repetitive, but the choreography repeats itself in 4-beat cycles, or (2) the dancer uses different choreographies at different times during the sequence.

Figure 5.16 shows the abstractions and dispersion measures obtained from the point clouds in Figure 5.15. The movements of the feet are more complex than the movements of the hands. Due to the fact that legs and feet support the dancer's body, feet movements tend to alternate between left and right. While one foot performs fast transitions between first and second beats (denoted by a spread of the 1/2-beat region), the other foot gives support and equilibrium to the space located inside the intimate space. This is characterized by low dispersion for the regions that correspond to the 1- and 2-beat levels (see Figure 5.16b). The combination of central position in the intimate space and commetric (non-syncopated) levels suggests a link between this musical quality and the body reference: relevant actions, such as important metrical levels, may be reinforced by muscular support

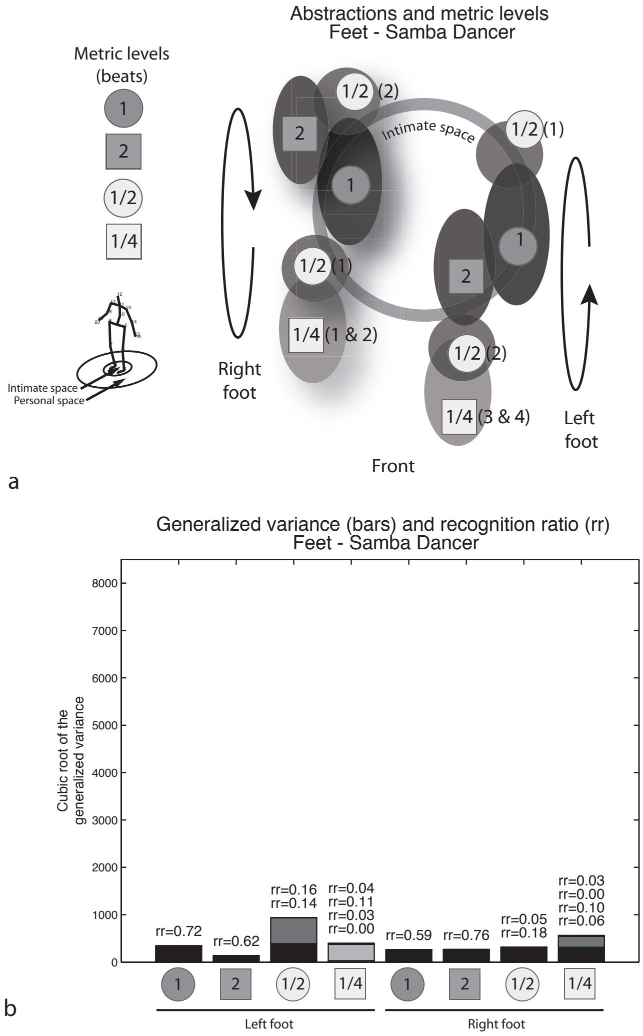

Figure 5.14: Abstraction of the feet movements in samba and measures of dispersion. The inner circle denotes the boundaries of the intimate space.

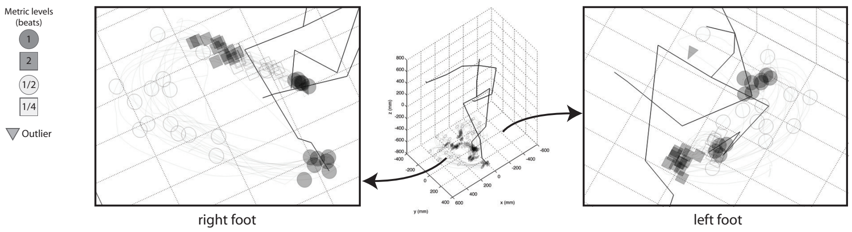

Figure 5.15: Detail of the point clouds for the feet gestures in Charleston. The axes on the 3D representations represent distance in mm. The points are represented by markers with a diameter of approximately 20 mm.

and equilibrium (see Lepelley et al., 2006, for examples of muscular effort in moving and static dance gestures). In the future, measures of rotation and muscle activity (EMG) may provide us with more information about the use of effort in such cases.

5.3.3 Expertise and dance: teacher and students

In what follows, we compare the left hand gestures of a samba expert with the left hand gestures of two samba novices, namely those of the teacher and students 1 and 2. Figure 5.17 (a, b, and c) displays the distribution of metric-based point clouds in the dancer's space, for the right hand only.

The data of the teacher's cyclical hand gesture reveals a region at the 2-beat level situated in front of the chest (top-right side, Figure 5.18a), with a slightly dispersed first beat region on the opposite side (bottom-left side, Figure 5.18a) and 1/2-beat regions in between. The data of the students' cyclical hand gestures reveal a structure that displays four distinct regions. However, the regions are slightly different from the teacher's, and students' regions differ from each other.

For example, for student 1 and 2, there is a tendency to place 1/2-beat regions at the horizontal extremity of the gesture, whereas with the teacher these regions exist at the top-left/bottom-right positions. The positions of the first and second beat are the same for the teacher and student 1. But student 2 locates these metrical cues inversely (there are no indications that dancers should assign metrical elements to specific sides). Both students seem to use the region in front of the chest, projecting 1/2-beat topologies in front in the right-most region of the hand gesture. The level of dispersion of the meter-related categories in the topology reveals other interesting idiosyncrasies (see Figure 5.19). Student 1 shows the highest levels of dispersion, especially for the 2-beat and 1/2-beat regions, which seem to be spread over the space of other levels in the vicinity. The spread of the point cloud over the periphery and center of the hand gesture (in a disc-like form, shown in Figure 5.17b) suggests that the student does not adopt the ring-like topology

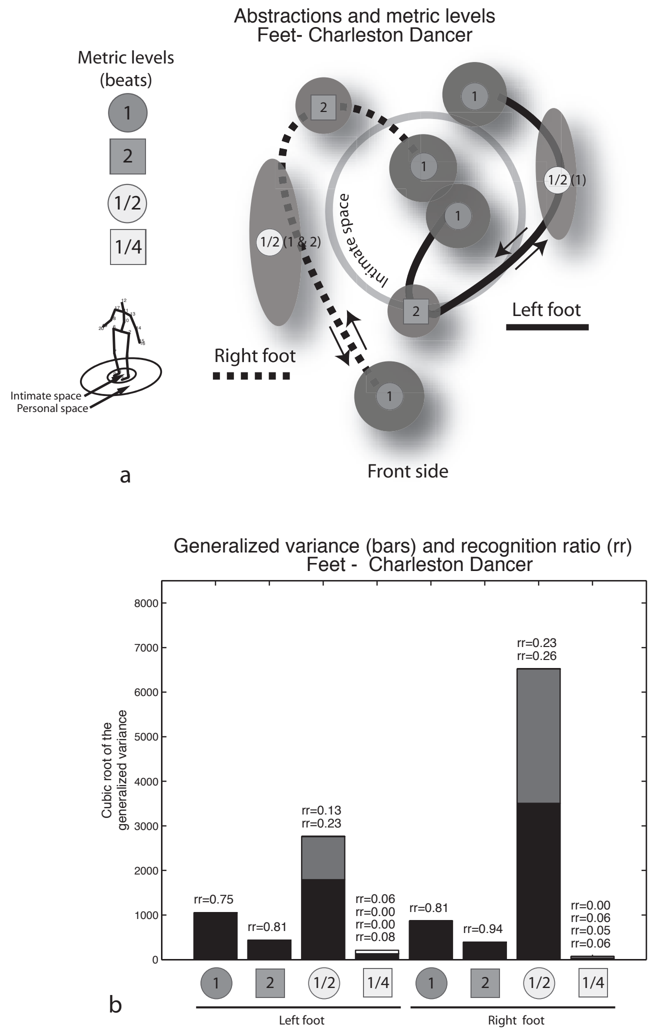

Figure 5.16: (a-b) (a) Abstractions of the feet gestures in Charleston dance. The inner circle denotes the boundaries of the intimate space. (b) Measures of dispersion.

(torus), which characterizes topological relations in samba (and Charleston) hand movements (see last sections). Conversely, student 2 exhibits a highly compact distribution of spaces, which demonstrates the redundancy of the movements in space and a predictable performance of the gesture.

The teacher's model seems to show an intentional organization of topologies marked by specific levels of dispersion and linear separations between topologies.

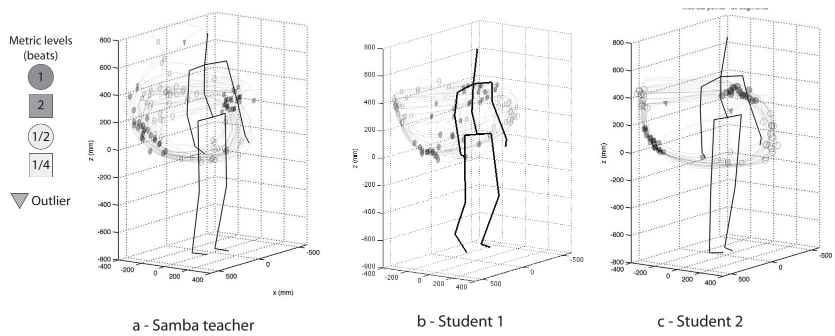

Figure 5.17: (a-c). Point clouds for the right hand (samba dance) of the (a) professional dancer, (b) student 1, and (c) student 2 are shown. The axes on the 3D representations represent distance in millimeters. The points are represented by markers with a diameter of approximately 20 mm.

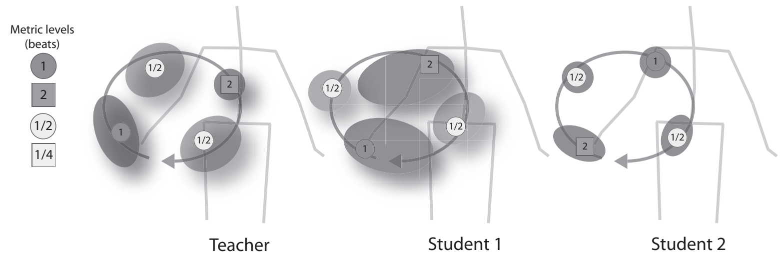

Figure 5.18: (a-c). Abstractions of the topological structures between the three dancers – teacher, student 1, and student 2.

The students were also able to manipulate different levels of these cues. So the mastery of stylistic forms of the teacher model seem to rely on intentional and specific choices of dispersion, orientation, convergence, and organization of space.

5.4 Discussion

With the TGA method, it becomes possible to quantify spatiotemporal frames of reference that are defined by focal points in space and time. These include the position of first and second beat with respect to the center and extremities of the body, and with respect to the low dispersion of the 1- and 2-beat levels, compared to the high dispersion of the 1/2-and 1/4-beat levels. In contrast, with the 1-and 2-beat levels, the spatiotemporal region between the first and second beat, as occupied by

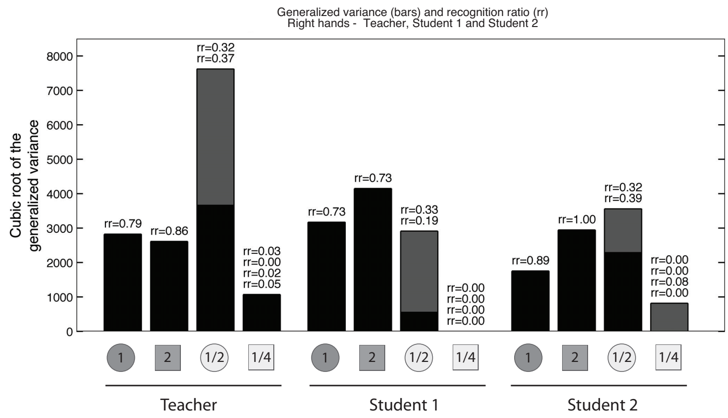

Figure 5.19: Generalized variance and ratio of recognition of points for the right hand – teacher and students.

1/2-beat spatial regions, seems to be used as an unintentional transition area, which is denoted by the high dispersion at this level in both dances.

In addition, the systematic use of extreme boundaries of the personal space and the center of the intimate space as 1- and 2-beat regions denotes how these musical cues are important qualifiers of a targeted body-centered reference frame for samba and Charleston. Interestingly, the TGA method reveals that the internal topology of the gestures in samba and Charleston encode the same relationship. However, the inter-relationship between hands showed a different phase synchrony, which implies that, in the end the presentation of gestures is very distinct. Other differences emerged from the discussion of the role of dispersion in the gestural topologies. In the case of samba dance, the dispersion of the first beat in the right hand might indicate a sort of hierarchy in the sense that if the first beat is not close to the intimate space, then its point cloud is more dispersed. Dispersion or gestural flexibility may therefore be linked with the peripersonal space. This is a salient characteristic of topologies found in the space close to the dancer's body, or found in proximity of the intimate space.

Feet topologies are particularly complex in both dances. Rhythm engagement, choreography, and functional support of the body are combined in the organization of feet dance forms. In Charleston, an interchange mechanism of support and action (support for the body and fast movements of the feet) seem to be structured in 4-beat cycles. The repetition of the first beat of the syncopation model, adapted to classify syncopations of 2-beat length, shows that the first beat is projected in front of the intimate space or behind, while the support is provided by the foot inside the intimate space. Further inspection of the video recordings shows that the supporting foot is subjected to rotations, which are not precisely described by a topology of spatial occupation. The combination of 2-beat hand periodicities with 4-beat feet periodicities match the 2/4 and 4/4 bar forms found in music for Charleston dances (foxtrot, swing, etc.). The topology of feet in Samba is also complex, but more symmetrical. Again, metrical levels are associated with support steps inside the intimate space but forward oriented projections indicate distinct contrametric regions.

The observations described above can be summarized in four statements that can be applied to samba and Charleston dances: (i) Boundaries of peripersonal space and proximity of the intimate space are strongly correlated with first and second beat topologies. (ii) The gestures seem to converge in commetric regions close to the intimate space and can be dispersed or flexible in contrametric regions that are distant from the intimate space. (iii) Hand gestures in samba and Charleston have similar topological structures. This may be explained by speculative hypotheses such as the inheritance of a common link with African roots, or a general cognitive basis of music-dance engagement. Idiosyncrasies mostly may be associated with shape structure, not depicted as topologies. (iv) Like hands, the spatial locus of 1- and 2-beat regions of feet gestures seem to occur at the boundary of the personal-space and the intimate space.

In the present study, the small number of participants limits the generalizability of between-participant comparison. However, what most people experience as the difference between teacher and student, namely, that the teacher's dance is (normally) more 'appealing,' or that the students' dance is 'imperfect,' is quite well reflected in the fine-grained characteristics of the meter-related topology, such as the dispersion/convergence, the relation with musical cues, and its precise organization in space and time. Although the topology of the students' hand gestures is similar to the teacher's hand gesture, the two students showed particular distortions that not only are characterized by higher levels of dispersion or deviation, but also by excessive convergence or precision. The level of dispersion of student 1 (what could be labeled as "lack of precision") and the excess of convergence ("too much precision") of student 2 clearly differ from the structure described in the topology of the teacher. The picture that emerges out of the present study is that in the students' gestures, the position of 1- and 2-beat topologies seems to be correct, whereas the position of the 1/2-beat regions seems to be distorted. In particular, for student 1 and 2, 1/2-beat topologies tend to be placed in the left- and right-most part of the gesture, while in the teacher model these regions are found in the top-right and bottom-left extremities. Apparently, the reference used to perform 1and 2-beat levels is consistent with the teacher's model, whereas the spatiotemporal intentionality of the 1/2-beat becomes less clear in the student's schema. The shift of the schema seems to be an indication of the fact that expertise may also involve the muscular control or auditory perception of 1/2-beat (and perhaps 1/4-beat) metrical cues and its relation to gesture.

The above observations can be summarized as follows:

(i) The synchronization of spatial positions of arms and feet with the first and second beat in music seems to be an initial stage of expertise. (ii) The imitation of stylistic positions and dispersion of 1/2-beat (and 1/4-beat) topologies may indicate a higher level of knowledge about, and expertise in, samba style. (iii) The sensorimotor control of the equilibrium between position, dispersion, and convergence of topologies in space may correspond with a higher level of choreographical skills, which includes the mastery of both motor control and parsing of musical/auditory information.

The extension and application of the Longuet-Higgins & Lee (1984) model as a spatiotemporal model for the analysis of the samba and Charleston dances can potentially contribute to gaining new insights about the modeling of meter in music for dance. In the extended model used in this study, different sublevels of the 1/2-beat metrical level were found that have different spatial distributions in the samba choreography. The differences pertain to spatial locations and they could offer further insight into the nonlinearities that were found in music, such as microtiming deviations on groove (Gouyon, 2007; Johansson, 2005; Lindsay & Nordquist, 2007; McGuiness, 2006; Naveda & Leman, 2009). In a similar way, feet gestures in Charleston extrapolate the 2-beat extension of the original model, suggesting a consistency with a 4-beat level cycle. The presence of a clear 2-beat level in the hand gestures and other metrical levels in other gestures suggests the existence of a spectrum of metrical levels in the coordination of body gestures.

The TGA method is the outcome of a number of studies that aim at developing analysis methods for musically driven gestures (Naveda & Leman, 2008a,b). The topology of features, which is about the relationships between point-cloud classes, can be straightforwardly linked with concept of basic gestures (which are called "basic gesture" in Leman & Naveda (2010); Naveda & Leman (2009). A basic gesture is linked with a mean geometric shape that underlies repetitive dance patterns onto which musical cues are projected. A basic gesture can be interpreted as a basic reference framework for the coupling of action (dance) with perception (music). In short, TGA looks at spatial occupation of musical cues, whereas basic gesture analysis looks at the basic forms that control spatial occupation. These two viewpoints of the gesture and its reference frames provide complementary tools for a better understanding of the interaction between body movement and music.

5.4.1 General discussion

The study of the corporeal deployment of dance gestures in response to music is a fundamental issue in embodied music cognition research (Leman, 2007b). A growing number of researchers are considering music cognition in terms of perception-action couplings (Stevens et al., 2009).

The coupling of music and dance by means of repetitive patterns often is observed in popular forms of dance. These forms seem to have evolved as inseparable elements in the development of musical cultures (Cross, 2001) and as a display of intentional behavior driven by music even if these dances no longer exist as an integrated part of social daily life (Hoerburger, 1968). In many cases, gestures became reference models, whose acquisition involved explicit rather than implicit learning, including reasoning about the representation of the performer's own body in space and time (Schneider et al., 2010). In many other examples of dance (including samba and Charleston), these relations are enriched by other modalities in a complex inter-textual phenomenon.

Interestingly, the aforementioned considerations about focal points and transition areas can be linked to the concept of gestural dynamics in musicology (see, for example, Godøy & Leman, 2010), the notion of equilibrium points in physical/physiological descriptions of action-perception couplings (Feldman, 2009b), or information theoretical approaches to guided action in relation to targets (Schogler et al., 2008). In addition, the gestural dynamics can be conceived in terms of body-centered reference frames, also called peripersonal space (Ghafouri & Lestienne, 2006) or kinesphere (Laban, 1928; Laban & Lawrence, 1947; Laban & Ullmann, 1966), and its proposed subdivisions: extrapersonal space, action-extrapersonal space, and ambient-extrapersonal space (according to Previc, 1998), or intimate and personal spaces (according to Hall, 1968, which are used in the present study). The TGA method is consistent with these approaches, and offers a general description method for dance/music couplings that can be linked with cultural studies.

The strength of this approach comes from the necessity to better represent the ecology of music and dance gestures in the analysis of dance styles. For the majority of popular dances, choreological and musical domains are often performed and experienced at the same time, but analyses often treat these domains as isolated processes. The first direct consequence of the attempt to reproduce this ecology is to use musical descriptors to transfer qualities to movements in space. The second consequence is to use the raw trajectories and the variability encoded in the movement patterns to infer qualitative information to the movement itself.

5.5 Conclusion

In this study, we explored how the spatial cognition of dance and music can be studied from a topological viewpoint. The application of meter-based musical cues to qualitative relations of the gesture space offers an approach for studying the relationship between musical cues are and corporeal expressions of perceived music. Samba and Charleston dances offer a context to study commonalities and differences in the spatiotemporal deployment of different cycles of repetitive gestures that underlie these dances at different levels of expertise.

The results obtained so far suggest that meter (used here as a musical layer over gesture) is encoded in the topology of the dancer's peripersonal space. Dancers use strategies of occupation of space that are strongly linked with musical cues, which forms the basis for re-creation of the idiosyncrasies of a style. This paper focuses on measures of spatiotemporal deployment of musical cues. These measures pertain to the dispersion regions that relate to categories of musical cues, and their spatial direction and position with respect to each other. It is shown that these measures carry important information about dance styles and levels of expertise.

The approach of the topological gesture analysis offers a straightforward bottom-up alternative to several traditional problems of gestural representation, and it can be used in several user-oriented applications.

Our method offers the promise of being able to capture both the body movement and the musical cues within a single representational framework. However, there are several issues that should be taken into account, such as: How does the brain keep track of these gestures? What musical features are actually driven by the dance gestures? How do we mentally represent our synchronized corporeal deployment in the proper spatial setting? How is the peripersonal space (the dancer's body-centered viewpoint) related to the surrounding space in which the dance is performed? How are dances perceived by audiences that listen to them and see them? These and similar questions are crucial when considering further issues such as learning abilities and memory training.

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6
Music Analysis

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Based on:

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- Naveda, L., Gouyon, F., and Leman, M. (2010). **Modeling musical structure from the audience: emergent rhythmic models from spontaneous vocalizations in samba culture**. In *Proceedings of the 11th International conference on Music Perception adn Cognition*, Seattle. University of Washington.

- Naveda, L., Leman, M., and Gouyon, F. (2009). **Accessing structure of samba rhythms through cultural practices of vocal percussions**. In Barbosa, A. and Serra, X., editors, 6th Sound and Music Computing Conference-SMC09, pages 259–264, Portugal.

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Abstract

(Main study)

Previous studies in Afro-Brazilian music have already pointed at basic characteristics of the samba music. These attempts to find invariant characteristics have been concentrated on symbolic descriptions of rhythm such as tonal and melodic contexts and not rarely stress two important characteristics: that samba music (1) is not easily decomposed in single elements from the musical context and (2) the musical experience in samba is strongly rooted on the perception of *timing*. In the first study of this chapter, we try to combine these ideas in an approach that looks at subtle characteristics of timing and how they are connected with other musical characteristics of samba music. We concentrated on how deviations microtiming interact with the metric structure of music, spectrum and intensity in the auditory domain. The feature detection was supported by a psychoacoustically based auditory model, which provided the low-level descriptors for a data set of 106 excerpts commercial samba music. A cluster analysis technique was used to explore patterns of microtiming deviations and amplitudes in different regions of the spectrum and different metric levels. The results confirm findings of previous studies in the field and introduce new elements that characterize microtiming in samba music.

(Complementary study 1)

In the second study (Section 6.7), we reapplied the methods for periodicity detection reported in Chapter 3 to the analysis of 106 excerpts of samba music. We used the same auditory model described in the first study of this chapter to generate a descriptor of the audio domain. These descriptors were analyzed with the method for periodicity detection described in Chapter 3 (Section 3.6), The results indicate that the music has an ambiguous profile of periodicities, which confirm the hypothesis presented in Chapter 3.

(Complementary study 2)

In the third study (Section 6.8), we applied the same methodology of the main study in this chapter to the recordings of spontaneous vocalizations recorded from musicians and non-musicians, in Brazil. The subjects were asked to describe samba rhythms with their voice, spontaneously. In both experiments (main study and complementary study 2) we found the same consistent profile of microtiming deviations and other tendencies of metric induction. The reproduction of the same pattern of microtiming deviations in vocalizations attests the striking coherence between perception and enaction in the samba culture.

6.1 Introduction

The idea that some properties are invariant in a group of music examples is a primary assumption in the analysis of music styles (Carvalho, 2000, p. 134). The majority of approaches to samba music have been concentrated on invariant properties collected through *subjective texts*: historical, anthropological and sociological information collected through texts, reports and interpretations from subjects. This large tendency points at the relevance of musical experience captured through informal contexts, oral history and subjective musical experiences. It searches for high-level information encoded in the holistic experience of music as depicted by musicians, composers and audience. A small part of the approaches looks at the *sonic* or *acoustic* texts of "samba music". It focus on the properties of sound, it looks at several different measurable qualities from which models can be proposed, generalized and compared. Both currents often reproduces the notion of "rhythmic priority", which permeates the analyses of the music from the African diasporas[1].

Apart from exposing a common place in the literature, the focus on subjective texts and the rhythmic priority aspects highlights two ways of understanding the samba culture: (1) that the experience of samba music is not easily decomposed in single elements from the amalgam of musical context and that (2) this experience is strongly rooted on the perception of *timing* and action in time. In this study, we tried to combine these ideas in an approach that looks at how subtle characteristics of timing are connected with a net musical characteristics in the multidimensional display of samba music.

6.1.1 Style and rhythmic characteristics of samba

Previous work based on symbolic representation (scores) of samba music have pointed at several hypotheses on the "deep structure" of the samba style. From the perspective of macro-time characteristics, it has been claimed that samba music is formed by a binary metric structure "muted" in the first beat and accentuated on the second beat (Chasteen, 1996; Galinsky, 1996; Moura, 2004). However, samba also exhibits a polymetric rhythmic texture composed of different metric layers having different periodic lengths and metric phases (Browning, 1995; Fryer, 2000). Rhythmic priority is claimed to perform a key function in the style and is identified as a direct link with African influences (Lima, 2005; Sodré, 1979). Authors have systematically proposed hypotheses of rhythmic characteristics that are supposed to be encoded in the rhythm structure of samba. The figure of "syncope" (Sandroni, 1996b; Sodré, 1979) is the "umbrella" concept that supports a series of syncopated motives such as the "tresillo" (Sandroni, 2001), the "characteristic syncope" (Andrade, 1991), the "tamborim cycle" (Araújo, 1992, quoted in Sandroni, 2001),

[1] What Kofi Agawu called the "*invention of African rhythm*" (Agawu, 1995), referring to analyses of African music.

the “samba rhythm necklace” (Toussaint, 2005), the “Angola/Zaire Sixteen-pulse Standard Pattern” (Galinsky, 1996; Kubik, 1979).

However, these characteristics seem to be too general to discriminate a style. Binary meter is not exclusive to samba. Syncopated lines, polymetric phrases and polyrhythms are also systematically performed in other styles. Even though all these hypotheses probably represent invariant properties in a considerable part of the repertoire, most of the researchers and musicians will agree that none of these options are systematically presented in the samba music or in the styles under the samba influence. In addition, most of the studies are not based on a representative number of examples samba music (see Gouyon, 2007, for an exception). Is there an invariant musical property that systematically encompasses samba music? Or style in samba can be only experienced through combinations of musical and and non-musical features in context?

Two hypotheses are analyzed here: (1) that microtiming levels of the metric structure exhibit invariant characteristics of samba and that (2) these characteristics form complexes with other features of the musical domain. In this study, we focus on the invariant properties of the *microtiming level* — the fastest level of the metric structure — and its relation with characteristics of intensity, meter and spectrum.

6.1.2 Microtiming

The lower levels of musical meter (e.g., bar, multiples of the bar level and beat levels) are related with large periodicities formed in the rhythmical texture (Sethares, 2007; London, 2004). They convey the Western-based concepts of bar and beat levels but also include larger structures such as polymetric phrases that extend across bars and other higher clusters of musical events. Although the temporal segments of these “macro-levels” encompass and organize many rhythmic events in single units, they do not directly synchronize with the information about the time points of these events. Higher metric levels (fastest metric levels) are less sensitive to large periodicities but are directly connected with great part (if not all) of the time points of the rhythmical events. Fastest levels of musical meter (microtiming levels) offer a temporal grid that supports virtually every element of the rhythmical texture. This metric level is referred in the literature in a variety of forms: “tatum layer” (Bilmes, 1993; Seppanen, 2001), “valeurs oprationelles minimales” (Arom, 1984), “pulsation” (Polak, 1998) or “common fast beat” (Kauffman, 1980). In this study we focus on small idiomatic deviations applied to the *tatum* level which are connected with the notion of *timing*. We call these deviations *microtiming*, here defined as a series of event shifts at a constant tempo (Desain & Honing, 1993; Bilmes, 1993).

Part of the previous literature on microtiming connected the study of microtiming deviations with the notion of movement induction, in special with the induction of *groove* and dance. Johansson (2005) studied microtiming and interactions with melodic patterns in Norwegian traditional fiddle music. Friberg & Sundstrom (2002) verified that eight-notes patterns are systematically performed in long-short patterns in jazz performances. The notion of swing in jazz and its correlations with pitch and phrasing were also studied in detail by Benadon (2003, 2006, 2009). Other studies tried to understand the notion of groove in different styles. McGuiness (2006) analyzed microtiming in different styles of music. Madison (2006) studied the consistence of the subjective grooving experience among subjects using music styles such as jazz, samba, Indian, Greek and Western African music.

6.1.3 Microtiming in Afro-Brazilian samba

Although the modulation of these microtiming shifts are perceived by humans (Repp, 1995; Gouyon, 2007; Repp, 1998), the time differences of such variations are too small to be analyzed in detail by means of score or ear. Most of the literature on microtiming is based computational audio analysis or results from experiments with precise modulation of timing by machines or computers.

Previous studies have been approached Afro-Brazilian music from the perspective of microtiming. Lindsay & Nordquist (2007) analyzed the microtiming of recordings of samba instruments (*pandeiro*, *surdo* and *agogô*) using FFT as basic feature detection. They found systematic anticipations 3rd and 4th 16th-notes (within 1 beat length) for the *pandeiro* recordings inside pairs of “short-long” onsets. They also found 4-beat length patterns of onsets in progressive acceleration. Naveda et al. (2009) studied spontaneous vocalizations of samba rhythms using an auditory model as feature detection and also found indications of systematic anticipations of the 3rd and 4th 16th-notes. Similar deviations were found by Lucas (2002) in a study about the traditions of *Congado Mineiro*, whose music is stylistically distinct from the samba styles but shares the same Afro-Brazilian roots. Lucas used standard spectrogram analyses to investigate timing in recordings collected in Minas Gerais, Brazil. Gerischer (2006) connected several reports from the musicians in the context of samba in Bahia with a systematic analysis of microtiming, based on field recordings. Differently from the other studies, Gouyon (2007) analyzed a large collection of commercial recordings using “complex spectral difference” (Bello et al., 2004) as basic feature and machine learning techniques to identify patterns in the microtiming structure. The results also indicate the existence of systematic anticipations of the 3rd an 4th 16th-notes.

This panorama accounts for evidences of systematic deviations that seem to occur on the 3rd and 4th 16th-notes in the beat level in samba music. However, with the exception of Gouyon (2007), all studies are based in very small set of observations. Analyses rely on windowed FFT methods, which do not offer reliable temporal definition for low frequency components. In addition, the notion of timing do not consider its interactions with intensity, timbre, pitch and macrotime cycles of metric periodicities. Can we confine "musical" timing in the domain of time, exclusively?

6.1.4 Multimodality in Afro-Brazilian samba

Afro-Brazilian music is strongly based on oral traditions and characteristics of African and Afro-Brazilian religious rituals (Carvalho, 2000; Sandroni, 2001; Sodré, 1979). The culture of samba inherits the relevance of the experience with timing from the "multiple experience flows" (Stone, 1985) that are intrinsic to these rituals. Gerischer (2006, p. 115) claims that the rhythmic experience in samba should be understood as a multidimensional process. This means that not only dance and music are involved, but also imagery, orality and other inter textual components. A typical description of an Afro-Brazilian Candomblé ceremony illustrates how this experience of timing unfolds in the music of the ritual:

> "The dancers dance with great violence, energy, and concentration. Getting really involved in the rhythm and movement (...) The drummers (...) can play certain signals in the rhythmic pattern to cause the dancing to take a violent turn (...) One method is for one drum to syncopate the rhythm slightly (another one maintaining it) such that a strong beat falls just before the main beat. (...) This gives a impression of increased speed when this is not really the case, and creates tension and feeling of imbalance in the listener or dancer" (Walker, 1973, quote in Fryer, 2000)

This example demonstrates how elaborated maps of timing and accents take part in a non obvious system of metric levels, polymetric lines, instrumental textures and in a mechanism of tension that cement sound and movement. Samba music derives from this ritualistic culture of music and movement, and these aspects seem to be crucial to understand and reproduce the rhythmic experience in Afro-Brazilian contexts or other cultural contexts influenced by African diaspora.

In this paper, we attempted to investigate the connection of timing with other musical dimensions using a method that is based on audio analysis. We focus on the study of interactions between timing, metric levels, intensity and spectral distributions from a data-set of musical audio. The methodology is specified in Section 6.3 along with a detailed account of our data-set, descriptors of musical audio and methods for clustering information. The results are displayed in Section 6.4, which examines the tendencies observed in the clustering groups.

6.2 Data-set

The data-set analyzed in this study consisted of 106 excerpts of music collected from commercial CDs (median of durations = 33 seconds). The range of genres covered by this sample includes music styles influenced by Rio de Janeiros samba, such as samba carioca, samba-enredo, partido-alto and samba-de-roda (Bahia). The excerpts were stored in mono audio files with a sample rate of 44.100 Hz / 16 bits and normalized by amplitude. Beat markers and the metric positions of the first annotated beat (1^{st} or 2^{nd} beat, 2/4) were manually annotated by 3 specialists using the software Sonic Visualizer (see Cannam et al., 2006)

6.3 Methods

The process of analysis involved four stages: (1) extraction of low level features (Section 6.3.1.1), (2) segmentation of spectral regions (Section 6.3.1.3) and metric segments (Section 6.3.1.4), (3) detection of microtiming events and (4) clustering of multidimensional information (Section 6.3.3).

6.3.1 Extraction of low level features

6.3.1.1 Auditory model

In order to provide a robust low-level feature for the representation of musical tessiture we used an implementation of the auditory model described in Van Immerseel & Martens (1992), implemented as a .dlib library for Mac OSX. This auditory model simulates the outer and middle ear filtering and the auditory decomposition in the periphery of the auditory system. The results take a form of loudness curves representing the loudness on the auditory bands of the audible spectrum (for more details see Van Immerseel & Martens, 1992, p. 3514). The configuration used in this study provides 44 channels of loudness curves with sample frequency at 200 Hz, distributed over 22 critical bands (center frequencies from 70 Hz to 10.843 Hz). Figure 6.1 displays an auditory image (or loudness curves) generated from the auditory model of the excerpt 22.

6.3.1.2 Segmentation

The segmentation phase involved two parts: (1) a process of segmentation of the spectrum range, which sums up auditory curves in 3 regions (low, mid and high frequency) and (2) three different levels of metric segmentation that generate the segments containing 1, 2 and 4 beats. Each metric level will be subjected to a separate cluster analysis, which results in clusters centroids for 1, 2 and 4-beat metric levels.

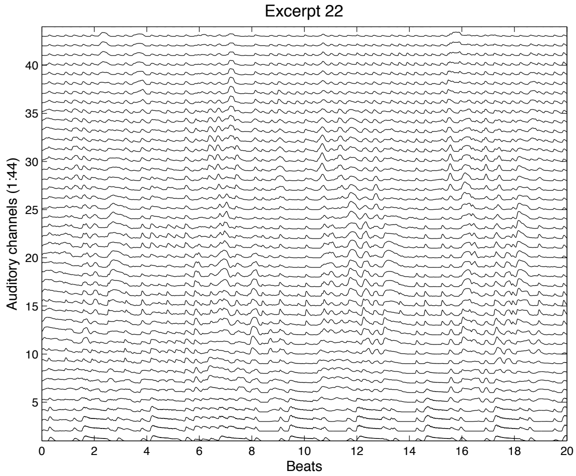


Figure 6.1: Loudness curves generated from the auditory model. The 44 envelope curves (0:1 x 44 channels) represent a simulation of loudness on each auditory channel.

6.3.1.3 Segmentation in spectral regions

The current knowledge about samba forms indicates that percussion instruments have defined musical functions and also roughly defined spectrum signatures across the musical tessitura. The musical function of each instrument is related to its timbre, which can be roughly represented by low-level descriptors in the frequency domain or, in our case, by loudness amplitudes in time distributed in auditory channels. For example, the spectrum of the low-frequency samba drum, the *surdo*, is mostly concentrated in the lower part of the audible spectrum. *Tamborims*, *repiniques*, vocal parts and other instruments occupy the mid frequency region of the auditory spectrum. *Ganzás* and different kinds of shakers will tend to occupy higher portions of the spectrum. Although the frequency components of these instruments will overlap each other in the time and in the frequency domain (particularly during transients in the attacks points), the spectrum signature of each timbre is relatively discriminated from each other. Figure 6.2 displays the analysis of the spectrum of four attacks played by four kinds of samba instruments and the distribution of central frequencies of the auditory model within the audible spectrum. Figure 6.3 displays the results of the analysis of each instrument in separate using the auditory model described in Section 6.3.1.1.

Each sound excerpt in the data set was processed by the auditory model, which resulted in 44 loudness curves (44 auditory channels). The loudness curves were averaged in 3 loudness curves that reflect estimated distributions of tessitura: low-

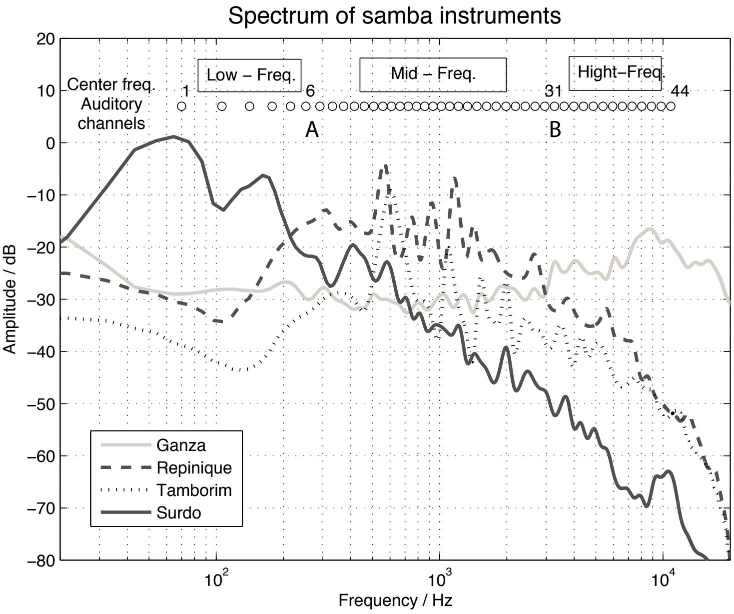


Figure 6.2: Spectrum analysis of a typical samba percussion ensemble (hamming window, 4096 points, 1/5 octave smoothing). The distribution of the central frequencies of the auditory channels across the frequency domain is indicated by the [o] marks (arbitrary amplitude). The divisions A and B indicate the segmentation of the auditory channels in 3 groups (low, mid and high).

frequency region channels 1:6, mid-frequency region channels 7:30 and high-frequency region - channels 31:44 (for a similar procedure see Lindsay & Nordquist, 2007).

6.3.1.4 Segmentation of metric levels

Current knowledge about the samba forms indicates that samba music has a well-defined beat level, a binary bar structure (2 beats) and a fast metric onset structure at a mathematical ratio of $\frac{1}{4}$ of the beat (known as *tatum* layer). Each metric element of the microtiming level will be referred as 16^{th}-notes (mathematical subdivision of $\frac{1}{4}$ of the beat).

In order to identify the time points of the metric levels, we performed the annotation of beat and bar levels for the entire data-set. Automatic beat annotation using softwares such as Beatroot (Dixon, 2007) and Sonic Visualizer (Cannam

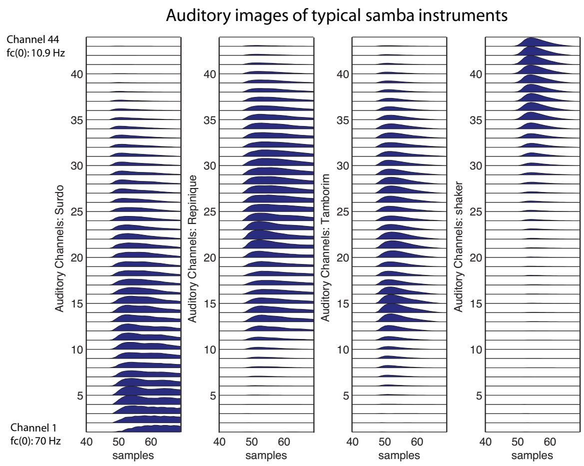


Figure 6.3: Response of the auditory model for the instruments *surdo*, *repinique*, *tamborim* and shaker. The graphs show the concentration of the spectra of each instrument in a specific region.

et al., 2006) resulted in poor beat tracking for this data-set. Therefore, we opted to combine manual and automatic approaches in a heuristics that looks for relevant peak events in the proximity of manual annotation (described in the next section). The division in metric segments was performed at time points provided by beat and bar manual annotation on the data-set. The process of both spectral and metric segmentation is displayed in Figure 6.4.

6.3.2 Extraction of event information

Each segment of the feature detection resulted from the segmentation of the metric levels (see Figure 6.4) contains the sum of the loudness curves for high, mid and low spectra. A temporary microtiming division is found via the mathematical subdivisions of these segments (4 subdivisions/beat). The deviations of the events from the positions resulted from the mathematical subdivisions convey the "expressive time" or microtiming deviations imposed by the performers. The heuristic used in this study searches for peaks around the mathematical subdivisions and selects the best candidates for each subdivision. Figure 6.5 displays the schema of the heuristic using the example of the metric level 1-beat, which has a *tatum* grid of 4 elements. A detailed description of the heuristic is displayed in the Table 6.1.

Note that the mean value between the position of the peaks of the three spectral regions in Phase 5 is of great importance in this context. The annotation does not provide a precise beat segmentation (due to bias of the manual process) and

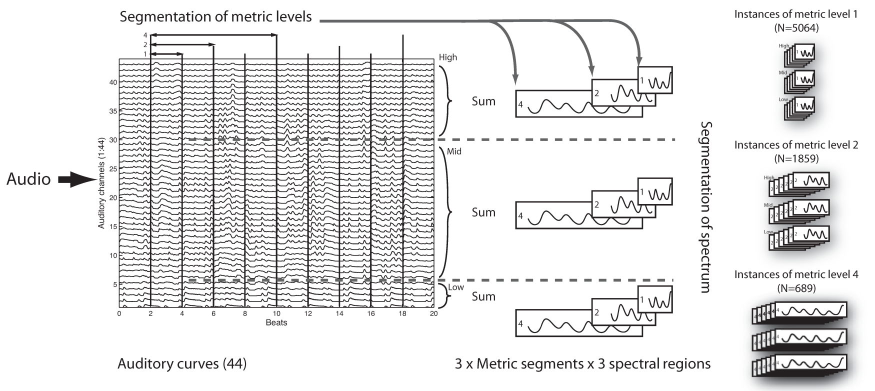


Figure 6.4: Two processes of segmentation of the auditory curves: metric levels and spectrum. The segmentation results in a collection of N instances for each metric level, divided by the spectrum region. The 3 spectral regions are also represented at this phase.

differences of attacks between spectral regions do not offer common point for segmentation (due to discrepancies between attacks of instruments). Therefore, we opted to rely on the average position of the three spectral regions of the 1^{th} 16^{th}-note, which permits the calculation of beat period and microtiming in relation to this point. In fact, it does not affect the results because we rely on relative positions in relation to the beat length rather than absolute positions in seconds.

This process results in a feature description of microtiming, represented by 2 kinds of descriptors: (1) the position of the peak (p) in relation with the metric layer and (2) the intensity of the peaks (i) organized in spectral regions (low, mid and high-regions) and analyzed for each metric level (1-, 2- and 4-beat levels). For n microtiming positions in a given metric level, the instances will contain p_{1-n} peak positions and i_{1-n} peak intensities at each spectral region r_{1-3}. Therefore, the structure of each instance of values that will be clustered depends on the metric level. The description displayed in the Table 6.2 specifies the structure of the instances for metric levels 1-, 2- and 4-beat.

6.3.3 Clustering of multidimensional information

In order to find interactions between these components, we carried out a k-means clustering based on an improved extension of the basic k-means algorithm, developed by Pelleg & Moore (2000) and implemented in Weka platform (Witten & Frank, 2009). This method searches for locations and numbers of clusters that efficiently improve the Bayesian Information Criterion (BIC) or the Akaike In-

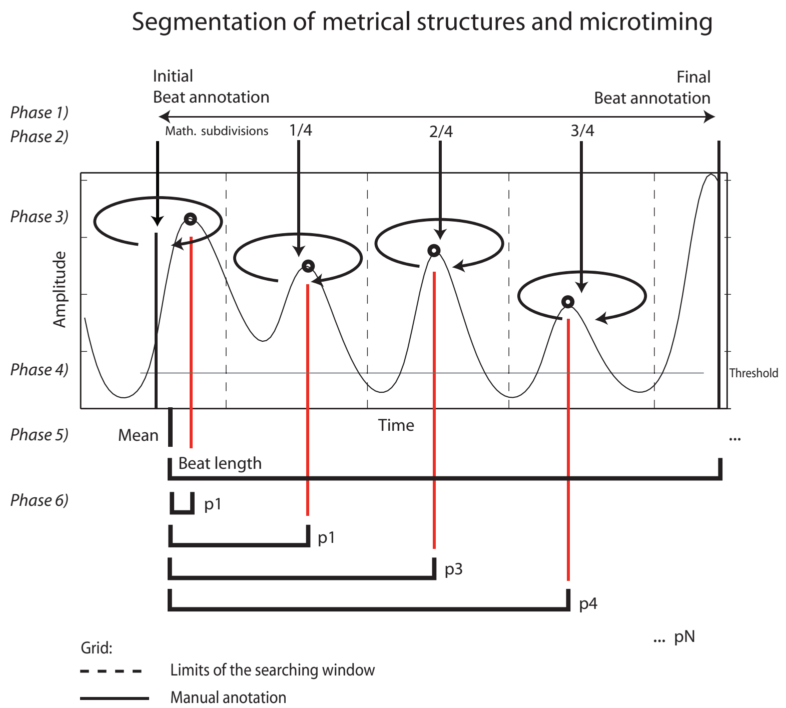


Figure 6.5: Description of the heuristic of calculation of microtiming deviations. See Table 6.1 for the explanation of each step of the algorithm.

formation Criterion (AIC) measure. The algorithm was configured to retrieve a minimum of 3 and a maximum of 5 clusters (arbitrary). Important observations within the results of cluster analysis will be accompanied by analyses of variance (ANOVA).

6.4 Results

In the sequence, the results of the clustering are displayed for each metric level. Peak positions are indicated as positions on a metric grid of 16th-notes (representing the subdivision of the beat in four sub-parts). Spectrum regions are referred as ‘s’, positions as ‘p’ and clusters as ‘c’ (e.g., peak position s2p4 in the cluster c3 indicates a the 4th peak position — 4th 16th-note — of the 2nd spectral region, mid-frequency). As to the representation of clusters, different clusters will be represented by different stem markers, connected by traced lines, which facilitates the visualization of the profile of the loudness of the cluster centroids. Ticks distributed along the horizontal axis of the graphs that represent cluster centroids (e.g., Figure 6.9) correspond to

Table 6.1 Phases of the heuristics for event detection

For each excerpt, for each spectral region, for each metric level,

Phase 1 Retrieve beat points and time interval of the actual metric segment from the manually annotated beats (e.g., inter beat interval, inter-bar interval).

Phase 2 Project the mathematical divisions of the microtiming points, here defined as $\frac{1}{4}$ of the beat length (e.g. inter-beat interval/4)

Phase 3 Look for the peaks in the proximity of/ within the range of manual annotation (length of the window = microtiming period)

Phase 4 Select a higher peak situated above a determined threshold (if there are no peaks above threshold, retrieve NaN).

Phase 5 Extract the mean peak position of the first peaks of the 3 spectral regions. Therefore, all positions (including positions in different spectral regions) have the same beat reference.

Phase 6 Retrieve position and amplitude of the highest peak in close proximity of the mathematical subdivisions.

Phase 7 Retrieve features: (A) the normalized length in relation with the length of metric layer, (B) peak amplitudes, metric levels (C) and spectral regions (D)

Table 6.2 Description of the instances used in the the k-means process

- Metric level 1 = $[p_{n1-4,r1-3}, i_{n1-4,r1-3}]$
  - (12 positions + 12 intensities =24 elements)
- Metric level 2 = $[p_{n1-8,r1-3}, i_{n1-8,r1-3}]$
  - (24 positions + 24 intensities =48 elements)
- Metric level 4 = $[p_{n1-16,r1-3}, i_{n1-16,r1-3}]$
  - (48 positions + 48 intensities =96 elements)

time intervals ranging from 13 to 62 ms (proportional to the range of BPM values).

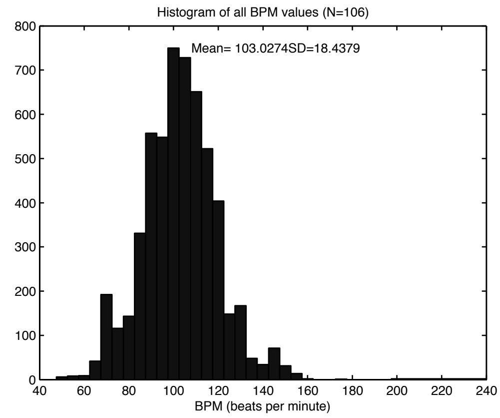


Figure 6.6: Histogram of BPM values of the beats for the whole dataset (106 excerpts, 5527 beats).

6.4.1 Data-set and tempo ranges

Figure 6.6 shows the distributions of the BPM values for the data-set ($Mean = 103.02/SD = 18.42$). The normality observed in the histogram show a tendency of tempi towards the 103 BPM, even though the range of BPM's is considerably large.

6.4.2 Clusters

6.4.2.1 Microtiming distributions in metric level 1-beat

The results displayed in Figure 6.7 show an overview of the main microtiming tendencies for metric level 1-beat. We examined the differences of all microtiming positions (4 positions x 3 spectrum regions) from the mathematical divisions of the beat using analysis of variance (ANOVA). The main observations derived from pair wise comparisons indicate that the means of the differences between 3rd and 4th peak positions and mathematical divisions (0.5 and 0.75 beat positions, respectively) are significantly anticipated from the other peaks ($F(10, 5527) = 422.39, p = 0$), which confirms results from previous studies (Naveda & Leman, 2009; Lindsay & Nordquist, 2007; Gouyon, 2007). These anticipations account for a mean deviation of 0.026, -0.031 and -0.032 beats for the 3rd 16th-notes (16, 18 and 19 ms, for the mean BPM in low-, mid- and high-spectrum regions) and -0.028, -0.018 and -0.027 beats for the 4th 16th-notes (16, 11 and 16 ms for the mean BPM in low, mid and high spectrum regions). In addition, the mean of differences of the first position of the low-spectrum (s1p1) are also significantly delayed from the mathematical

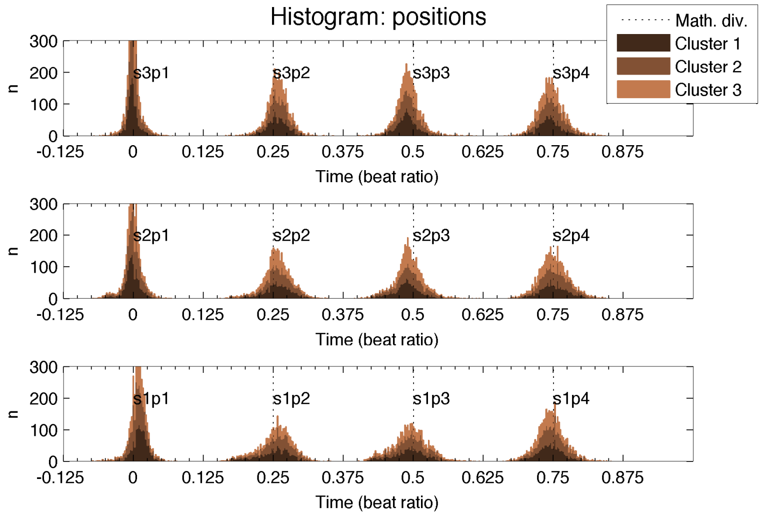


Figure 6.7: Distributions of the peak positions for metric level 1-beat, for all excerpts (N=5527, 106 excerpts). The shades of gray indicate the contribution of each cluster to the total distribution. The vertical grid indicates the mathematical subdivisions of the beat (0, $\frac{1}{4}$, $\frac{2}{4}$ and $\frac{3}{4}$ of the beat).

division (0 beat position). We have found a mean deviation of +0.012 beats, which represents 7.3 ms for the mean BPM of the data-set. The closest peaks to the mathematical divisions of the beat are s1p2 (mean diff.=.0032 beats) and s2p2 (mean diff.=.0024 beats).

The following sections will examine the internal structure of these distributions by means of clustering analysis (K-means clustering) in different metric levels. In these sections, we investigate if different combinations of features coexist in the variability exhibited in the distributions shown in Figure 6.7.

6.4.2.2 Clusters in metric level 1-beat

The cluster analysis of the 2-beat level resulted in three clusters for each spectrum region, displayed in Figure 6.8. The representation of the cluster centroids shows the systematic observations discussed in Section 6.1.3: 3rd and 4th 16th-notes are anticipated in all three spectrum regions and in all three clusters, first 16th-note of the low-spectrum is slightly delayed. However, the configuration of intensities shows new information. Pair wise comparison after repeated analysis of variance (ANOVA, mean cluster intensities x 3 spectrum regions) shows that the 2nd 16th-note is significantly accentuated in the mid- and high-spectrum for all clusters

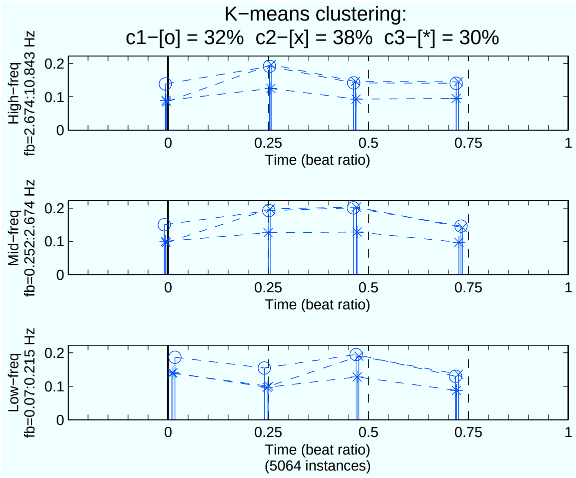


Figure 6.8: Cluster centroids of 3 clusters and 5527 instances (beats) - metric level 1-beat. Ticks represent 0.05 beats, in a temporal range between 13 and 62 ms. Vertical traced lines indicate mathematical divisions of the beat.

(means: sp1=0.12, sp2=0.17, sp3=0.17, $F(2, 3821) = 675.7201, p < 0$). In the higher spectrum, the clusters show flat amplitudes in second half of the beat. Cluster c3 is generally less intense than the other clusters while cluster c1 is more intense. Cluster c2 seem to display a mixture of clusters c1 and c3: first peaks have the same properties of cluster c3 while the other peaks exhibit the same characteristics of cluster c1.

6.4.2.3 Clusters in metric level 2-beat

Figure 6.9 shows clusters c1, c2 and c5 for metric level 2-beat. The results exhibit the same systematic anticipations of 3^{rd} and 4^{th} 16^{th}-notes and a delay of the 1^{st} 16^{th}-note in the low-frequency region seen before. These microtiming deviations seem to affect the two beats at the bar level and show the same temporal range at the metric level 1-beat. Analysis of variance (ANOVA) showed that the mean of deviations of all clusters from the mathematical positions of the 1^{st} 16^{th}-notes of the first and second beat are significantly different ($F(1, 802) = 15.2181, p < 0.0001$), resulting in +0.0087 beats for the first beat position and +0.018 beats for the second beat, low spectrum.

Peak intensities reveal more variability in this metric level. While the peak of second 16^{th}-note seems to be accentuated only in the mid-frequency region (1^{st} beat), the fourth 16^{th}-note is accentuated in the clusters c2 and c5. However, in the 2^{nd} beat, peak amplitudes of the 2^{nd} to the 4^{th} 16^{th}-notes are flattened. Cluster

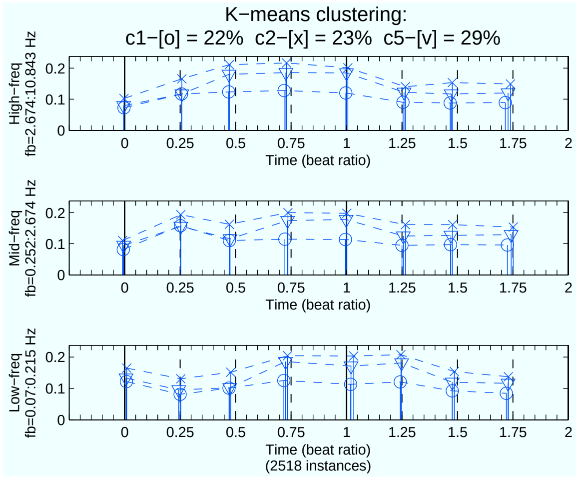


Figure 6.9: Cluster centroids of 3 clusters and 1859 instances (clusters 1,2 and 5, 2-beats). Ticks represent 0.05 beats, in a temporal range between 13 and 62 ms. Vertical traced lines indicate mathematical divisions of the beat.

c1 has an overall low intensity and flat profile compared with the other clusters. Figure 6.10 shows the results of the clusters c3 and c4. These results differ from the clusters displayed before by the profile of increasing deviations accumulated during the time.

Cluster c3 shows an increasing anticipation in all regions and peaks. The anticipation increases until the last 16^{th}-note of the 2^{nd} beat, which ends with almost 0.1 beat of anticipation (from the mathematical rule at 1.75 beats). Cluster c4 shows the opposite pattern: an increasing delay from the first to the last 16^{th}-note. The amplitude patterns seem to be similar to the observed amplitudes in clusters c1, c2 and c5.

6.4.2.4 Clusters in metric level 4-beats

The clustering for the metric level 4-beat resulted in a solution of 5 clusters. Figure 6.11 shows the centroids of clusters c1, c2 and c3 and Figure 6.12 shows the results for clusters c4 and c5. The metric level 4-beats includes all the main characteristics observed in metric levels 1- and 2-beat, with special attention to the deviations of peak positions. The profile of peak loudness seem to be quite similar for all clusters, including clusters c4 and c5, displayed in Figure 6.12. The differences between clusters c1, c2 and c3 seem to reflect differences between profiles of peak intensity. Cluster c2 seem to be more attenuated while cluster c2

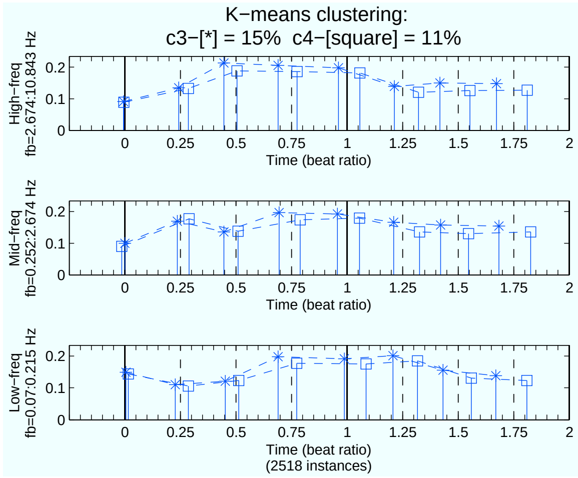


Figure 6.10: Cluster centroids for 2 clusters and 659 instances (clusters 3 and 4, metric level 2-beats). Ticks represent 0.05 beats, in a temporal range between 13 and 62 ms. Vertical traced lines indicate mathematical divisions of the beat.

displays the higher loudness curves.

Figure 6.12 displays the results for clusters c4 and c5, which convey the same pattern observed in the metric level 2-beats (Figure 6.10). Results for cluster c4 indicates that 27% of the instances are grouped in a continuous acceleration profile that reaches up to mean=-0.12 beats of anticipation in the last peak position (high spectrum, ANOVA $F(2, 597) = 2.8646, p < 0.057$) from the mathematical rule. Although the deceleration pattern of cluster c5 represent only 19 % of the instances the last peak position in this cluster reaches up to a mean of -0.18 beats in the last peak onsets (105 ms for the mean tempo = 103 BPM). We applied analysis of variance (ANOVA) to the mean differences of the mathematical subdivisions for each cluster (3 mean spectrum regions), displayed in Figure 6.13. The data shows a significant tendency of accelerations and decelerations but also and increasing level of variance. The microtiming positions that mark the beat (positions 1, 5, 9 and 13 on Figures 6.13a and 6.13b shows less tendencies of deviations, which may denote an impulse to maintain the beat level less affected by the deviations in microtiming.

6.5 Discussion

The systematic anticipation in the 3rd and 4th 16th-notes in all metric levels and spectral regions seem to confirm the existence of a systematic artifact described in

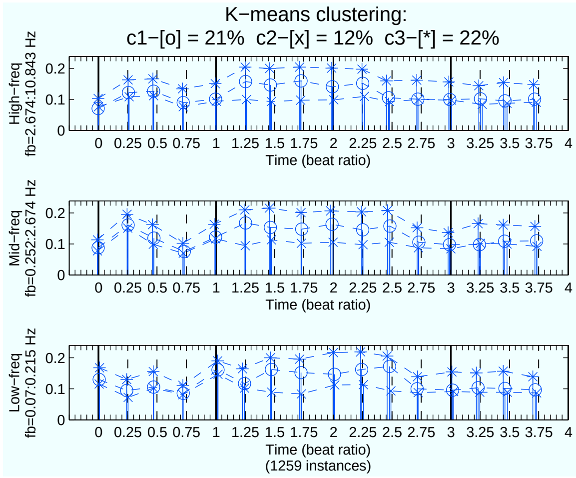


Figure 6.11: Cluster centroids for 2 clusters and 659 instances (clusters 3 and 4, metric level 2-beats). Ticks represent 0.05 beats, in a temporal range between 13 and 62 ms. Vertical traced lines indicate mathematical divisions of the beat.

previous studies about microtiming in samba music (Gerischer, 2006; Lindsay & Nordquist, 2007) and other Afro-Brazilian musical traditions (Lucas, 2002; Gouyon, 2007). Variations of these peak positions seem to be greater than 0.025 beats but smaller than 0.05 beats, which means range of anticipations between 10 and 52 ms of the mathematical division of the beat (0.5 and 0.75 beats).

The delay of 1st 16th-note positions in the low-frequency region of the spectrum for all metric layers shows a phenomenon not mentioned in previous studies. It is well know that commetric beat patterns in samba are performed by percussion instruments such as *surdo* or *tantã*, which are accentuated in the 2nd beat (Sandroni, 2001; Moura, 2004; Chasteen, 1996) (also reflected in our results). However, we were unable to find references to any systematic delay of such percussion instruments.

The delay of 1st 16th-note positions must be interpreted attentively. The temporal range of delays in the low frequency region is very close to the sample period of the auditory model (5 ms), which means that minimum significant delays found in the Figure 6.9, for example, account for only 2-samples (10 ms) between the mathematical rule and peak position. More research is needed to support this observation.

The occurrence of linear and crescent deviations, demonstrated in Figure 6.10 and Figures 6.11 and 6.12, must be also interpreted with attention. The computation of clusters may have merged two recurrent tendencies of outliers in the data set.

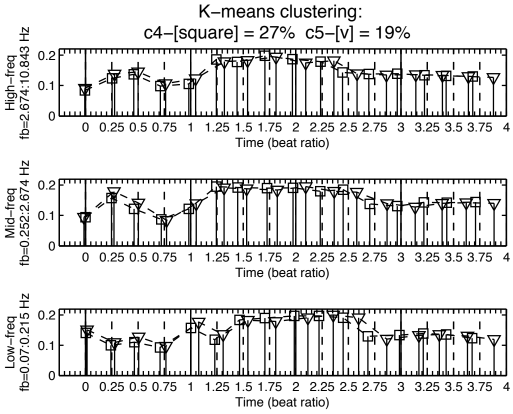
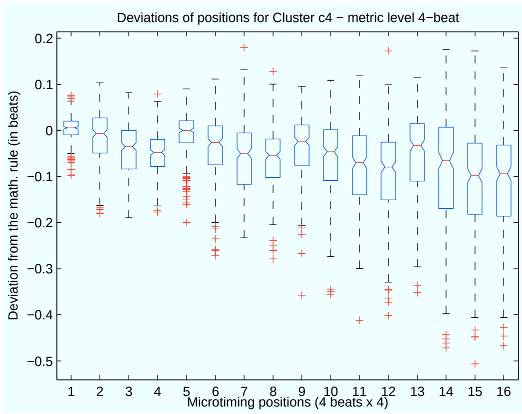


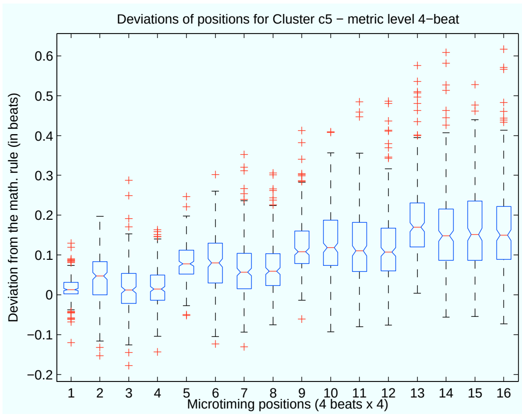
Figure 6.12: Clusters c4 and c5 for the metric level 4-beat.

However, the percentage of the instances represented by these clusters (c3-15% and c4-11%), and similar cluster structures found in other metric levels above 2-beats (4-beats level) and the significance of these distributions (see Figure 6.12), indicate that they reflect real microtiming structures represented in our data-set. If this hypothesis is confirmed, the presence of these clusters may indicate that musicians use rhythmic devices similar to *accelerando* and *ritardando* forms, at microtiming level. Although these rhythmical artifacts are widely used to delimit phrases, endings and formal articulations in classical music (macro-time level), it is surprising that such devices appear at this level of time structures. The range of these deviations indicate that they are less clearly defined than the ones used in classical music, which may configure a new microtiming device.

The variation of amplitudes demonstrates that microtiming in samba is subjected to interactions with accents and meter. The flatness of 16th-note amplitudes observed in clusters in all metric levels, especially the 2-beat level, indicate the existence of metric cues encoded in the amplitude of microtiming structures. While the first beat starts with a low-energy 16th-note in the low-frequency region and accents in the 2nd (Figure 6.8) and 4th peaks (Figure 6.9), the 2nd beat starts with a characteristic strong bass accent, followed by flat and low intensity 16-th notes. This oscillation of multidimensional characteristics between beat positions may play an important role in the induction of metric properties.



(a)



(b)

Figure 6.13: Mean deviations from the mathematical subdivisions for clusters c4 and c5.

6.6 Conclusion

In this study we analyzed the interaction between microtiming, meter, intensity and spectrum. The results confirm the tendency of anticipations of the 3rd and 4th 16th-notes at the metric level of 1 beat. It also shows the presence of two new rhythmic devices that may characterize samba forms: (1) a small delay of the lower spectrum and (2) systematic forms of *accelerando* and *ritardando* at a microtiming level. Peak amplitudes display two characteristics: (1) the induction of systematic accents in the 3rd and 4th 16th-notes of the first beat (metric level 2-beats) and (2) mechanism that interacts with energy between metric structures and spectral regions. These mechanisms seem to signalize several metric levels at the same time (e.g., 1-, 2- and 4-beat levels). The use of a psychoacoustically based feature as the main descriptor of the audio domain suggests that these observations may be available as proximal cues in the periphery of the auditory system. Moreover, the results show that microtiming can be understood as a multidimensional device of musical engagement. At the same time it creates tension by disrupting the flow of the *tatum* level it keeps the structure metrically organized by signalizing other metric levels. This signalization is realized by means of recurrent patterns shown in the amplitudes and the periodic structure of microtiming deviations.

The present study does not intend to show an exhaustive overview of multidimensionality of microtiming structures in Afro-Brazilian music. Other important interactions inside and outside the auditory domain may influence the process. More research is needed to elucidate the role and the magnitude of these findings within the perception of groove induction, interaction with dance gestures and recognition of style.

Acknowledgements

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6.7 Complementary study 1: Analysis of periodicity in samba music

6.7.1 Introduction

This study is conveys an analysis of periodicity in all excerpts of the data-set of commercial music studies in the previous sections. In Chapter 3 (Section 3.8.1.2) we compared the analyzes of periodicity in 6 excerpts of samba dances and 3 excerpts of samba music using a cross-modal methodology that allowed comparisons between movement and audio data. Here, we expand the analysis of music to the 106 excerpts present in the data-set of commercial music. A complete description of this data-set is displayed in Section 6.2.

6.7.2 Analysis and results

The methodology is described in detail in Chapter 3, Section 3.6. It consists in the analysis of periodicities present in all auditory curves provided by the feature detection described in the Section 6.3.1. After the generation of the loudness curves provided by an auditory model from the audio excerpt (44 auditory channels), the auditory image (collection of auditory curves) is segmented in 16-beat length parts. Each auditory curve of each part is analyzed using the *Any-Route* algorithm. This algorithm (see description in Section 3.6.2) provides a measure of the importance or response of the periodicity for each metric level. It is based on an non-orthogonal method for periodicity analysis that calculates the ratio of energy (norm) extracted from the signal by the periodicities. Since the measurements are taken from a non-orthogonal decomposition of periodicities, beat level 2-beat may contain energy from metric level 1-beat and metric level 4-beat may also contain energy from metric levels 1- and 2-beat.

Figure 7.19b displays the results of the analysis accompanied by analysis of variance (ANOVA) for all the curves extracted from the data-set of commercial music. These results confirm the analysis realized in few musical excerpts displayed in Figure 3.15, Chapter 3. The results show a portrayal of periodicities that does not exhibit strong tendencies in terms of metric periodicities. Although the samba is considered as a form of music based on binary meter, the periodicities at level 2-beat are not considerably stronger than beat and 1.5-beat levels and significantly weaker than metric levels 3-beat and 4-beat. The impact of these results and the comparison with the same analyzes realized in the movement domains will be discussed in Chapters 7 and 8.

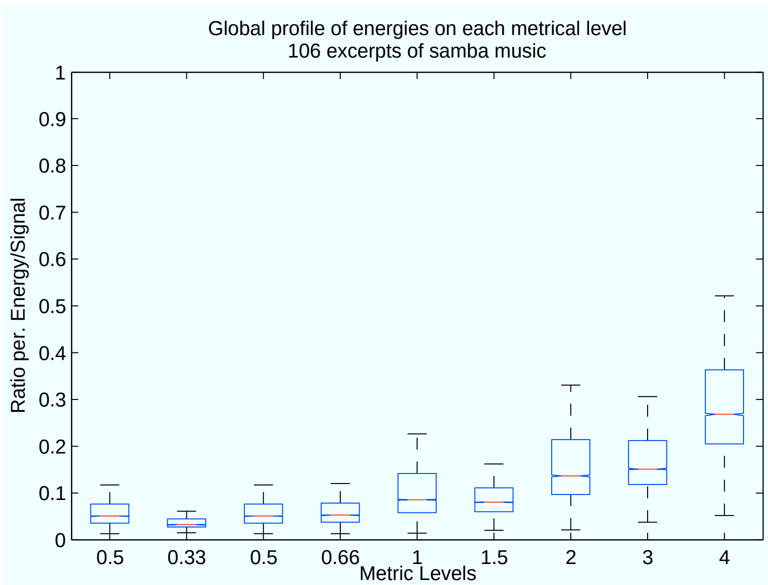


Figure 6.14: Profile of the ratio of energy in the metric levels for 106 excerpts of samba music ($F(8, 74044) = 6696.3433, p < 0$).

6.8 Complementary study 2: Microtiming in spontaneous vocalizations of samba culture

6.8.1 Abstract

In this study, we look at forms of vocal percussion in Brazil as a way to retrieve musical characteristics entrained by subjects in samba culture. We recorded a data-set of vocal percussions collected from randomly selected Brazilian subjects. The data-set of recordings was processed using a psychoacoustically inspired auditory model and further analyzed using the same methodology displayed in the last study, in Section 6.3. The analyses of rhythmic patterns show intriguing similarities with the findings in previous work, in which the methods were applied to excerpts of commercial music. The results attest that microtiming is a significant characteristic of the Afro-Brazilian samba and may represent an important form of rhythmic engagement, not well described in the current literature.

6.8.2 Introduction

Beatboxing, *Puirt-a-beul* and *bols* are some of the examples of vocal percussion forms found in different cultural backgrounds. These practices generally make use of non-meaningful phonemes for imitating instruments and often rely on onomatopoeia (Stowell & Plumbley, 2008; Atherton, 2007). Previous knowledge about forms of vocal percussion accounts for examples distributed over different musical cultures and practices, which range from simple devices for musical learning to elaborated forms of performing art. Vocal percussion may have differentiated from melodic singing due to the necessity for more freedom in expressing rhythmical ideas. It is also possible that it originated from the combination of a vocal apparatus in human species and the necessity of rhythmical expression in all human cultures. However, what makes these forms of vocal percussion relevant to our study is the use of the voice as a seamless link between musical intentionality and acoustic energy. In this study, we use this link to access rhythmic intentionality and analyze patterns of microtiming in Brazilian samba.

6.8.2.1 Vocal percussion

Cultural forms of vocal percussion have been rarely mentioned in musicological research. More recently, the emergence of *hip-hop* in the cultural sector has shed light on the *beatboxing* form, which is only a modern and geographically limited form of vocal percussion. Other examples found in the bibliography approach music forms in India (*bols*), song genres in Ireland (*Puirt-a-beul*), pedagogic devices for conga teaching in Cuba (Atherton, 2007) and verbal art in Africa (Hunter, 1996). So far, vocal percussion seem to assume diverse socio-cultural functions and importance, although only a small number of dispersed scholarly and non-scholarly records have looked at it in detail.

In computer music, some attention has been devoted to the potential use of vocalizations, in special pitch based vocalizations in Western music contexts. The easy assessment of user's musical intentionality for music retrieval applications appears to be a central element in the *query-by-humming* approach. During the last years, a number of publications and implementations have been produced in the field (see Typke et al., 2006, for a review of algorithms). A small number of studies approached forms *vocal percussion* from this perspective. Kapur et al. (2004) used the beatboxing as a mechanism to retrieve and analyze drum loops and their rhythmical structures. Nakano et al. (2004) developed a similar approach focused on native Japanese speakers as subjects, which demonstrates the application of the approach in phonetically different backgrounds. Kang & Kim (2007) used vocal percussion in the real-time animation of motion clips (dance animations). Although most of these studies aim at understanding how vocal queries relate with musical databases, in very few academic work the opposite is shown, namely, how vocal queries are related with subjects conceptions of musical forms.

Heylen et al. (2006) studied spontaneous vocalizations to access internalized models of tonality. The subjects were asked to sing along to several music pieces in different tonal contexts. The results show the emergence of major and minor tonal structures that resulted from spontaneous vocalizations. The use of vocal apparatus to retrieve the tonal evaluation from subjects is understood as a corporeal articulation in response to different tonal stimulus. The insightful turn of vocalizations into corporeal articulations offers an interesting perspective: it opens channels to less formalized responses to music, which include not only vocalizations but also body movement. The framework of embodied music cognition (see Leman, 2007b), in which this concept is developed, seem to adapt more naturally to the problems of musicological investigation developed in less-formalized musical cultures. The music and dance traditions of the samba culture are examples of cultural artifacts dominated by informal learning and practices, in which our universe of study is delimited.

6.8.2.2 Vocal percussion in samba

Samba music is generally described as having a binary meter music form accentuated in the second beat, and a rhythmic texture that is characterized by syncopated rhythms (Salazar, 1991; Chasteen, 1996; Mariani & Asante, 1998; Sandroni, 2001). The music is only one component of an intricate complex, in which forms of dance, music, poetry, rituals and social relations develop mostly through in an informal context (Sodré, 1979; Fryer, 2000).

Ziriguidum, *balacobaco* and *telecoteco* are some of the very common onomatopoeic expressions used in Brazil. They are not easily found in dictionaries and scientific literature but they are intuitively linked with symbolic elements of samba, behaviors and culture. Expressions like these appear in thousands of internet references (mostly in Brazilian Portuguese): blog posts[2], discussions [3], books[4], little enterprises, dance clubs, restaurants and others. Surprisingly, there are almost no references on the use, functions and definitions of vocal percussion as a common practice. To what extent is this practice common in Brazilian society? Which characteristics of this form of vocal percussion are consistently aligned with samba music? How do they reflect the element of the samba style within the acculturated population?

In this preliminary study, we concentrate on the last two questions. By analyzing a database of vocal percussions recorded from randomly selected Brazilian subjects, we aim at grasping information about the models entrained by the subjects and enacted in these vocalizations. The database of audio recordings was analyzed using a psychoacoustically inspired auditory model and further processed with exactly the same methodology described in Section 6.3, where we analyzed commercial samba music. In the Section 6.8.6 we discuss the results, rhythmical structures derived from the analysis and compare them with results of previous studies.

6.8.3 Data-set

The data-set was recorded in Brazil between 2008 and 2010. They were complemented with questionnaires that provide better information about socio-cultural profiles of the subjects (not analyzed in this study).

The recording sessions took place in four different locations in Belo Horizonte (Brazil) and INESC-Porto, in Porto (Portugal), in relatively quiet spaces (classrooms). In order to create conditions to access practical measures of how the practice is present in the universe of study, we opted to randomly choose Brazilian subjects, either passer's-by or students selected in international courses in Porto.

First, the subjects filled out a brief contact form. No information about the study was provided before the recordings. In the sequence, the subjects were invited to use the voice to demonstrate what they consider to be samba rhythms, using their voice in spontaneously organized sequences. These sequences were registered in one single take. We registered the subjects that refused to perform or declared her/himself unable to perform the task. No training sessions or repeated takes were used in this experimental model. The recordings were realized with a professional digital recorder and high-quality microphones, using a sample definition of 44100 b/s at 16 bits (stereo), stored in SD cards.

[2]About 61700 occurrences in Google, October, 2010
[3]About 3480 occurrences in Google, October, 2010
[4]About 1170 occurrences in Google Books, October, 2010

6.8.4 Method

6.8.4.1 Segmentation and normalization

The audio excerpts were segmented manually. The criteria for segmentation consisted in selecting and extracting homogeneous excerpts that last a minimum of 4 or 8 beats. Each excerpt was normalized at 0 dB (amplitude) and the channels merged into mono aural WAV files. Although female and male voice differences may have an influence on the overall auditory images, we opted to avoid any kind of spectral normalization or further processing aimed at normalizing these differences.

6.8.4.2 Processing

The audio excerpts were processed using the same methodology used to process excerpts of commercial samba music, described in Section 6.3. As such, the methodology involves extraction of low level features, segmentation of spectral regions and metric segments, detection of microtiming events and clustering of multidimensional information. In order to look at the microtiming deviations in detail we also processed timing information in separate. In this complementary study we only looked at metric level 1-beat, distribution of tempo and clusters.

The results will be displayed using the same nomenclature and structure displayed in the results in Section 6.4. The K-means algorithm used in this study was also based on Pelleg & Moore (2000) and configured to search for best ratings between a minimum of 2 and a maximum of 10 clusters. We processed 670 instances of 1-beat length.

6.8.5 Results

We processed a total of 109 recordings, recorded from 71 subjects. The median age of the subjects was 25 years, 78% of the subjects were male, 22% female. Five subjects (7%) refused to perform any form of vocalization. 17% of the subjects reported no musical experience. 18.7 % of the subjects that reported any sort of musical experience considered that their activity as “hobby” while 28% reported being subjected to informal learning. 37% of the subjects considered themselves “professional” musicians.

6.8.5.1 Tempo distributions

Figure 6.15 presents the histogram of tempi for the whole data-set. The mean BPM value (BPM=100.9), shape and standard deviations (SD=20.6) are very similar to the same information collected from commercial recordings (Mean= 103.02 / SD=18.42), displayed in Figure 6.6.

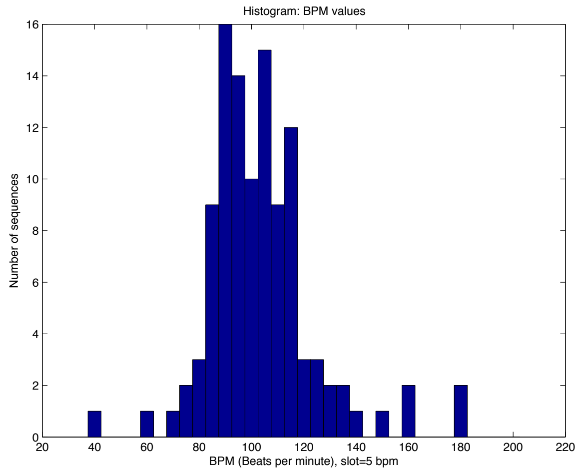


Figure 6.15: Histogram of the tempi of the vocalizations (Mean BPM = 100.9, SD = 20.6).

6.8.5.2 Clustering

Figure 6.16 shows the representation of clusters obtained from the k-means analysis for metric level 1-beat (N=670). In this process, all the information concerning timing and intensities of the spectrum region curves was fed into a k-means clustering configured to retrieve best cluster configurations between 2 and 10 clusters (see Pelleg & Moore, 2000, for more information).

The results show rather constrained clustering choices (2 clusters) which may have been caused by random distributions, bias and noise in the data. The results of microtiming positions show the same tendency seen in commercial recordings: all the spectra of the 3rd and 4th 16th-notes anticipated in relation to the mathematical rule (.5 and .75) and the low spectrum of the 1st 16th-note delayed. This striking similarity with the results from the commercial recordings is confirmed by the distributions seen in Figure 6.17 which demonstrated the distributions and level significance of for the whole data (there is no cluster visualization in this figure). An analysis of variance (ANOVA) also confirmed the results displayed in this graph ($F(11, 3167) = 10781.5751, p < 0$).

Figure 6.18 shows how loudness peaks do not follow a clear tendency. It can be said that there is small tendency of higher peaks in the mid-spectrum that grows from the 2nd 16th-note up to the peak on the 4th 16th-note. Although this information was confirmed by analyses of variance ($F(11, 5386) = 60.3528, p < 0$) the effects are marginally explained the tendencies in the graph (high SS error) and cannot be fully supported.

Figure 6.19 shows the result of cluster Pelleg's implementation of K-means

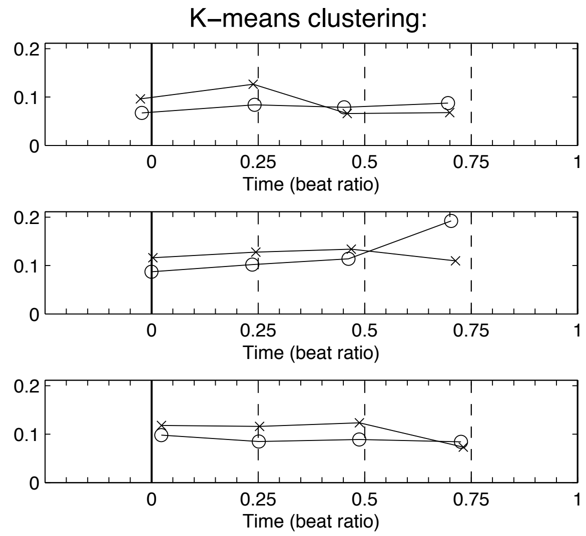


Figure 6.16: Cluster centroids for 2 clusters and 670 instances (beats). Ticks represent 0.05 beats, in a temporal range between 13 and 62 ms. Vertical traced lines indicate mathematical divisions of the beat.

(Pelleg & Moore, 2000) configured to retrieve a range between 2 and 10 clusters. The algorithm retrieved 10 cluster combinations displayed here in the vertical axis (no information about peak intensity is analyzed here). These results confirm in great extent the tendencies of anticipations of the 3rd and 4th 16th-notes and delay of the 1st 16th-note in the low-spectrum.

6.8.6 Discussion and concluding remarks

In this study we have investigated a form of vocal percussion present in the Afro-Brazilian samba culture but rarely studied in the scientific literature. We collected vocalizations from a random selection of subjects in public spaces in a experimental setup that allowed subjects to spontaneously describe samba rhythms with their voice or refuse the proposed task, if necessary. In the analysis, we have focused on the analysis of microtiming deviations and how they are linked with patterns of intensity and spectrum. These descriptors provide an general account of the timing, accents and types of the emissions (spectrum) used by the subjects to realized the vocal percussion. The methodology reproduces exactly the same procedure applied in our previous studies based on commercial samba music.

The results show two striking similarities and several intriguing differences between the data-set of commercial music (CM) and the data-set of vocalizations (VOC).

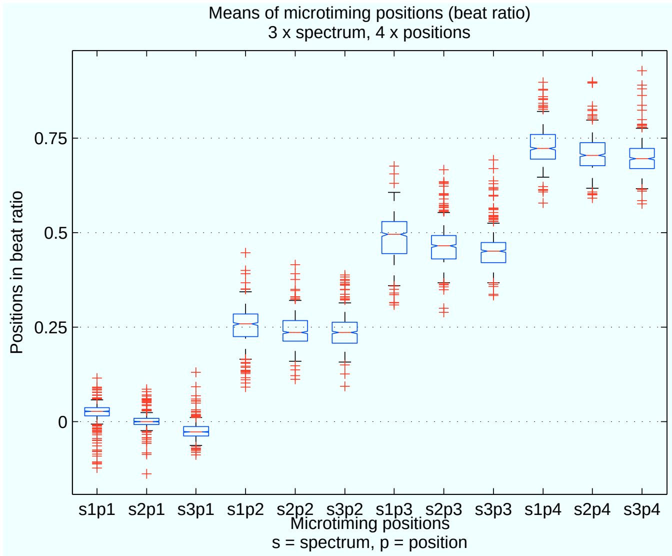


Figure 6.17: Distributions of positions for each spectrum region (s) and position on the metric level 1-beat (p) ($F(11, 3167) = 10781.5751, p < 0$).

The mean of the tempo curves of the vocalization differs in merely 2 beats from the mean BPM in the commercial recordings. In addition, the variance illustrated by the shape of the distributions and the standard deviations is also very similar (SD(CM)=19.4, SD(VOC)= 20.6). Such similarity would not represent any relevant observations if, for example, the mean BPM's of both data-sets were situated around the tendencies at 120 BPM, reported in Van Noorden & Moelants (1999). In such case, one could argue that 120 BPM forms an "universally" preferred tempo due to bio-mechanical or cultural issues. However, the strong correlation of the mean's tendency around 100 BPM and the similar variance between the two distributions seem to demonstrate the mirroring between tempo in commercial music and spontaneous vocalizations.

The second striking similarity is regarded to the systematic microtiming deviations found in both data-sets. Note that not only the tendency of anticipation of the 3rd and 4th 16th-notes in all spectrum regions is mirrored but also the slight delay in the low-spectrum of the 1st 16th-note. These deviations do not exceed more than several tens of milliseconds but are significantly reproduced by subjects, musicians and non musicians. How these expressive timing characteristics are exchanged between the music in the society, the subjects' ability to grasp cues and vocalizations? Why microtiming deviations exhibit such a level of similarity?

The curves of intensity do not provide significant information about tendencies in the data-set. Tendencies in the 1st 16th-note and 4rd 16th-note show some dif-

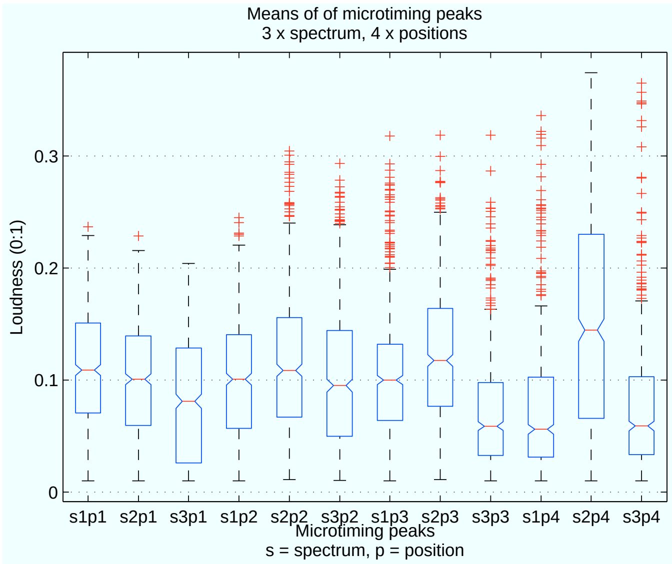


Figure 6.18: Distributions of the peak intensities (0:1) for the each spectrum (s) and position (p) for all the data-set. Note that clusters are not discriminated in this figure ($F(11, 5386) = 60.3528, p < 0$).

ferentiations but the level of noise and variance in the data-set only permit some speculations. An inspection in the audio files did not only show a collection of different modes of accentuation and use of vocal emissions without clear groupings. More research is needed in order to approach these modes in a proper way that takes into account genre differences and a methodology for discrimination of vocal emissions.

This study complements the work on microtiming in Afro-Brazilian music described in the last sections. By looking at spontaneous vocalization of musicians and non musicians we consistently demonstrated a loop between stimuli, perception and enaction in the samba culture. The role of the microtiming in the theory and representation of musical rhythm may require new considerations on how we represent style, expressiveness and rhythmic structure. More research is needed to understand if these features are exclusive characteristics of the samba culture of if microtiming engenders similar processes in other musical cultures.

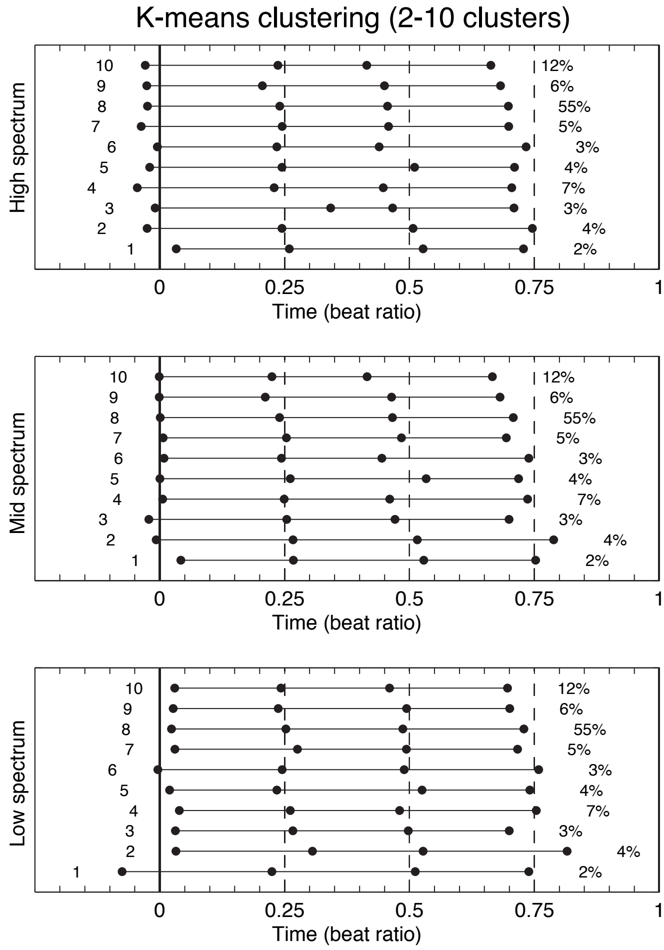


Figure 6.19: Clustering applied to the peak positions (only timing information) present in the data-set. Note that Pelleg's implementation of K-means (Pelleg & Moore, 2000) retrieves 10 clusters of microtiming positions in a initial configuration of 2 to 10 clusters.

7

Basic Gestures and Topologies in a Panorama of Samba Dances

Abstract

In this chapter, we investigate the characteristics of the gestures of samba dances. We focus our study on characteristics that are related to musical meter and how they are organized according to the similarity between gestures and according to different profiles of dancers. We analyzed a data-set of 30 motion capture excerpts of samba dances, danced in *samba-no-pé* style and performed by 15 professional samba dancers (Brazilians). The recordings were analyzed with two complementary methodologies: (1) the *Basic Gesture* approach (BG), which focus on the shape of the gesture; and the (2) *Topological Gesture Analysis* (TGA), which focus on qualities of the space, or topologies of gestures in space. The results of the basic gesture approach were further classified using a combination of Procrustes and quadratic discrimination analyses. The classification revealed similarities between the shape of the dance gestures and in relation to the tempo and profiles of gender and choreographic background of the dancers. The results show a wide panorama of personal sub-styles and and confirm hypotheses delineated in earlier studies in this dissertation.

(*Complementary study*)

During the experiments with few dance and music sequences re-

ported in Chapter 3 (Section 3.8.2.2), we suggested that the metric structure encoded in both domains could be studied through the analysis of periodicities in movement and sound signals. In this complementary study, we analyzed the periodicities that support the metric structure of all joint trajectories of the motion capture recordings described in the previous study by means of the same methodology implemented in the Chapter 3. The results are compared with the same analysis realized on audio, described in Section 6.7.

7.1 Introduction

In the previous chapters, we proposed two methods for the analysis of gesture in popular dances (Chapters 3, 4 and 5): the *basic gesture* approach and the *topological gesture analysis*.

The first method, called *Basic Gesture* approach, has a focus on the *shape* of the dance gestures. It provides a representation of the *shape* of the movement trajectories, which reflects the periodicity in the movement and informs about the relation of this periodicity with the signal. It delimits a precise pattern in space and it is sensitive to the level of periodicity in the signal. The second method, called *Topological Gesture Analysis* or simply *TGA*, has a focus on the space that is occupied by the gestures. The method provides a representation of regions in the space, which results from the points in the trajectories that are synchronized with metric cues of the music. In other words, it focuses on the spaces abstracted from shapes and on the relation between musical cues and the dance gesture in space. The TGA is sensitive to the variability and redundancy of the dance gestures.

In previous studies reported in Chapters 3, 4 and 5, these two methods were tested with few subjects. In the present study, we extend the universe of observation to a group of 30 dance excerpts. We focus on the description of general characteristics of samba dance and on how differences between gesture shapes and gesture topologies depend on gender, tempo and choreographic background of the dancers.

This study is organized as follows. In the Methodology part (Section 7.2) we describe the recordings and further procedures realized in the experiment. In the sequence, the analyses and results are divided in three parts: (1) *topological* analyses, (2) *basic gesture* analyses and (3) *gesture classification*. In the *topological* analyses (Section 7.3), we describe the method and the results of the analysis of the data-set using the TGA approach. In the basic gesture analyses (Section 7.4), we display the method and the results of the application of the basic gesture approach to the same data-set. In the gesture classification (Section 7.5), we describe the methods and the results for the classification of the maps of basic gesture representations resulted from the previous section (Section 7.5).

7.2 Methodology

We recorded the dance performances using a motion capture system (Optitrack/-Natural Point) that consisted of 12 cameras positioned around a squared aluminum structure (4 x 4 meters) and a computer workstation. Each session was 60 s in length and was recorded at a frame rate of 60 Hz, interpolated to 100 Hz in the editing phase. The motion capture recordings were synchronized with the audio stimuli using low-latency audio trigger (10 ms of latency) connected to a infrared light signal. The recording sessions were edited in the ARENA software (Natural Point) and exported as C3D files. The files were imported into Matlab by using the MoCap toolbox (Toiviainen & Burger, 2010). The calculation of basic joint positions of the body, filtering of raw vectors, normalization and part of the visualization functions were also based on the MoCap toolbox.

The dancers wore a dance suit with 34 reflective markers attached to it; the markers provided the point-set representation of body morphology. The markers were placed on the head (3), upper arms (3 + 3), upper back (3), hips (4), hands (3 + 3), thighs/knee (2 + 2), shins (1 + 1), and feet/toe (3 + 3). The stimuli used to perform the samba dances were composed of looped samples of a samba percussion ensemble (*surdo*, *tamborim*, and *caxixi*). The samples were recorded from professional samba musicians in Brazil, using a multitrack recorder. Two stimuli were used to accompany the dancers: one sequence performed in 80 BPM and one sequence performed in 120 BPM. The beat and tatum levels (1/4 beat) of each stimulus were manually annotated in order to provide the metric cues necessary to implement the methods (see discussion about meter in samba in Section 2.3.1).

7.2.1 Normalization

We performed two processes of normalization in all samples of motion capture data. (i) In the first process, we normalized the maximum distance between the lowest sample of the feet and the highest sample of the head (Z coordinate) to 1,70 m, for all dancers. This process did not affect relative proportions between body segments but provided an acceptable normalization of different body morphologies. (ii) In the second process, the raw trajectories were normalized with respect to a referential point and orientation of the dancers body (the point is defined as the centroid of the body across markers and the orientation as a frontal view with respect to the left and right hips). This normalization extracted the effect of whole body translations and rotations and provides a better conextualization of the movements of the dancer in the peripersonal space (see definition of peripersonal, intimate and personal spaces in Section 5.1) .

7.2.2 Subjects

The recordings were mostly realized in the cities Belo Horizonte and Salvador (referred elsewhere as BH and SA), in Brazil. The cultural background of the samba dancers in Belo Horizonte (BH) belongs to choreographic matrix of the Rio de Janeiro's samba. The background of the dancers from Salvador (Salvador is the capital of the Bahia state) exhibit specific characteristics that differ from the dances from Rio de Janeiro. Dance and music from the region of Salvador and Bahia are denominated *Bahian* style.

Fifteen Brazilian subjects participated in this study. All participants were professional samba dancers with more than 5 years of experience in teaching or performance in dance. The recordings were mostly realized in Brazil (one dancer was recorded in Belgium). 60% of the subjects (18 recordings) were female while 40% were male dancers (12 recordings). 60% of the subjects (18 recordings) belonged to the cultural background of the "Rio de Janeiro" samba while 40% (12 recordings) belonged to the background of "Bahian" samba. 53% the of excerpts (16 recordings) were danced in 120 BPM and 47% of excerpts (14 recordings) were danced in 80 BPM.

7.2.3 Tasks

All subjects danced pairs of sequences in "samba-no-pé" dance style, performed at 80 BPM and 120 BPM. One subject danced two excerpts in 120 BPM (Dancer 1, Excerpts 1 and 2). The same subject danced two specific forms of samba — "samba-de-caboclo" and "samba-quebrado" — claimed by the subject as being close to the Afro-Brazilian religious forms of dance in Bahia. Dancer 10 (excerpts 21 and 22) also reported the influence of dances experienced in the Afro-Brazilian cults.

After a period of adaptation to the recording setup, the dancers were asked to perform examples of the basic dance forms in *samba-no-pé* style (see Sections 2.3.2 for more information) within a defined circular area (diameter = 4 m) in a relatively isolated environment. They were asked to avoid improvisational turns in the body orientation (frontal performance, in relation to a single direction).

7.2.4 Analysis

The analysis involves 3 parts: (1) the process of generation of TGA representations, (2) the process of generation of Basic Gesture representations and (3) the process of gesture classification based on the Basic Gesture analysis.

In the first two parts, the results provide compreehensive representations of dance gestures for each excerpt of dance, according to the basic gesture and TGA analyses. These maps are displayed in the Appendix A (TGA) and Appendix B (BG). The analyses and results of the TGA approach will be reported on the next section (Section 7.3). The analyses and the results of the Basic Gesture approach will be reported in the sequence and will be further complemented by a process of gesture classification. The process of classification involves Procrustes and discriminant analysis, described in Section 7.5. In the process of gesture classification we compare the maps of basic gestures in order to unravel similarities and dissimilarities between groups in our data-set.

Both BG and TGA approaches make use of musical cues extracted from manual annotation of the stimuli. These cues inform about the metric structure of the music and are based on a model of musical meter adapted from Longuet-Higgins & Lee (1984), displayed in Figure 7.1. The figure shows the classical division of the metric levels in hierarchies and a distribution of metric levels in phases, as discussed in Section 5.4. Further references to metric levels in the course of the methodology will be based on the division of metric levels in levels and phases presented in this model.

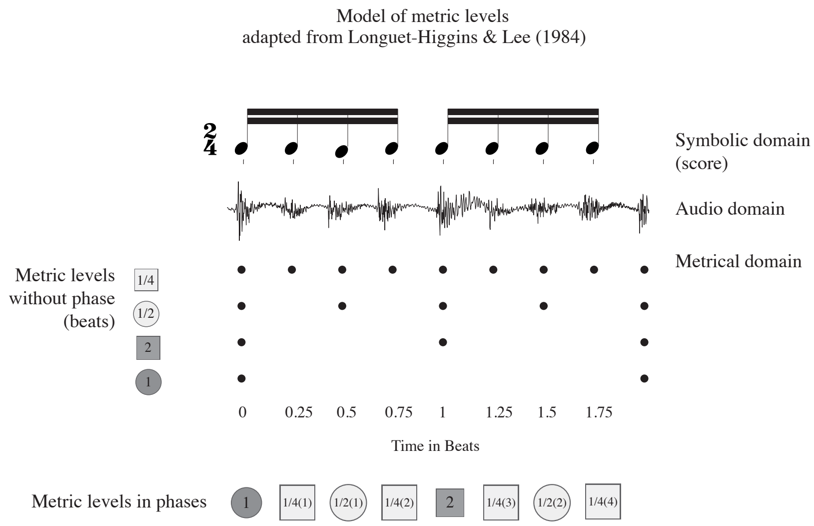


Figure 7.1: Hierarchy of metric levels adapted from Longuet-Higgins & Lee (1984). Two concepts are displayed in this model. (1) On the left side of the graph, we display a traditional view of musical meter as a hierarchical structure containing metric levels 1, 2 , 1/2 and 1/4. (2) On the bottom part of the graph we display an extended hierarchical structure that convey the phases of each element of the metric levels, as discussed in Section 5.4.

7.3 Topological gesture analysis of samba dances

The extraction of features using Topological Gesture Analysis (TGA) involves the procedures proposed in Chapter 5 with several improvements. The method applied here consists of (1) segmentation, (2) normalization, (3) projection of cues, (4) discrimination of point clouds and an additional process of (5) generalization of topological abstractions in *convex hull* representations.

7.3.1 Segmentation and discrimination

In the process of segmentation, we segmented a set of 32-beat sequences from the original motion capture recordings, audio sequences and audio annotations. A homogeneous 32-beat sequence was manually selected and normalized (see description of the normalization procedures in Section 7.2.1). The metric cues were classified from the annotated beat and tatum points using the model of metric hierarchies (see Figure 7.1), which generates a set of time stamps and categories o meter, as exemplified in Figure 7.2. Since motion capture and audio data were synchronized in the recordings, the metric categories can be projected onto its respective time points in the trajectories of the body joints. This process generates *point clouds* spread in the peripersonal space of the dancer.

In the discrimination phase, the point clouds were classified using a quadratic linear classifier, which was trained with the original categories of meter (the process is illustrated in Figure 7.2). This results in a set of corrected classified points separated in space by quadratic boundaries (such as ellipsoids or paraboloids) and a set of incorrectly classified points (error). The level of dispersion of the resulted point-clouds was computed as the *generalized variance* of the set of points. The proportion of points that were correctly classified by the quadratic boundary is indicated by the *ratio of recognition* (all these process were explained in detail in Chapter 5). Since our categories reflect a conceptual structure of musical meter, these point clouds indicate regions in space where categories of musical meter occur in the choreographic space.

7.3.2 Topological abstractions

Topological abstractions are regions defined in space of the dancer that represent qualities projected onto the point clouds. In this study, the topologies represent the metric levels of music that are synchronized with the dance gestures. In Chapter 5, the topological abstractions were implemented through simple graphical illustrations. In this study, the abstractions are automatically generated from the point clouds, which are transformed in 3-dimensional polygons. The transformation of point clouds into polygons can be realized in several ways but it basically implies on defining a form in which point cloud can be generalized in space. For example,

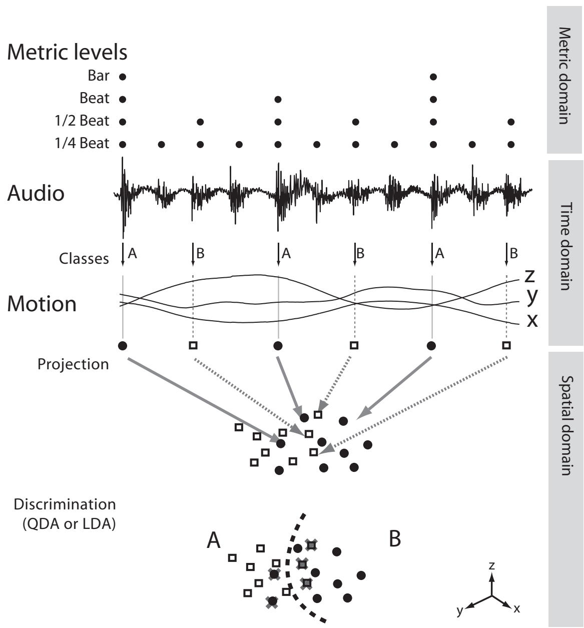


Figure 7.2: Process of projection of the point clouds. In the top graph, the representation of metrical hierarchy of the music is illustrated along the time-domain. The categories are projected on the spatiotemporal domain using the time position of each category, which results in *point cloud* distributions in space. Further discrimination of these clouds can be realized using a number of discrimination techniques. The discrimination process results in spatially discriminated point clouds that carry the quality of the projected cue.

one could assume that a topology is represented by a geometrical boundary around the point cloud such as spherical, ellipsoidal or polygonal forms (see Carlsson, 2009, for an overview of the theory behind it). In this study we assume that the points that define the boundary of the point clouds form a polygon that represents the topological region. We define this polygon as a *convex hull*, which is the minimal convex set containing the point cloud.

Figure 7.3 displays two point clouds and their relative convex hull's. Although such polygons offer other additional features such as volume and position descriptors in the Euclidean space, we will only focus on the topological relationships of the topologies with the dancers' bodies[1].

[1]In Lobato et al. (2010), for example, we used a spherical distribution to transform point clouds into topological representations. From this simplified generalization we derived a compressed representation of dance that provided a model for re-synthesis of dance movements

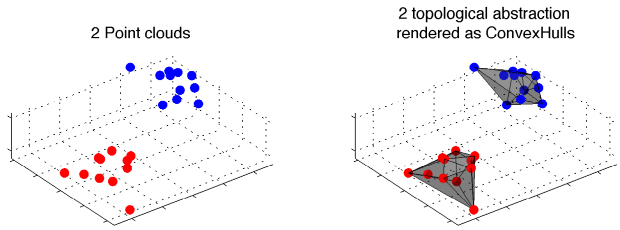


Figure 7.3: Two point clouds and their respective *convex hull* polygons formed by boundaries of the point clouds.

7.3.3 Overview of topological analyses

The representations of the topologies and their characteristics for all 30 excerpts are displayed in the Appendix A. Figure 7.4 (top and bottom-right graphs) shows the topologies of 6 joints, for the excerpt 8. Different colors indicate the metric levels, levels of transparency are (inversely) proportional to the ratio of recognition. The topologies are plotted against a stick-figure and accompanied by numbers that indicate the metric levels (1-, 2- and 1/2 (1 and 2)-beat). The numbers in the parentheses besides the indication of the metric levels (e.g., 1/4(**2**)) represent the *phase* of the metric level, as described in Figure 7.1. In the bottom-left graphs we indicate the generalized variance (bars) and ratio of recognition (*rr*, above the bars) for each topology.

This compact representation of topologies reveals several interesting characteristics of the dance gestures. For example, in Figure 7.4, the gestures of the right hand of the dance excerpt 8 are not only larger, but more dispersed than the gestures of the left hand. This is evidenced by the size and relative positions of the topologies as well as by the levels of generalized variance (dispersion) displayed on the bottom-right part of the figure (non-symmetrical hand gestures can also be verified in excerpts 5, 6, 7, 8, 9, 17, 18, 19, 27, 28 and 30). Gestures of the right hand seem to be more precise in the spatiotemporal structure because they are less dispersed (lower generalized variance) but also very predictable (higher *rr*). Note that the sequence of 1-, 1/2(1)-, 2- and 1/2(2)-beat levels in space indicates that the circular movement of the left hand is counterclockwise (from the perspective of the reader) while the movement of the right hand is clockwise.

It is also important to look at the relationships between topological regions and the space used by the dancer's body. For every beat, one hand approximates to the intimate space[2] while the other hand is projected towards the periphery of the

[2]See page 127, for a definition of personal spaces in the context of dance.

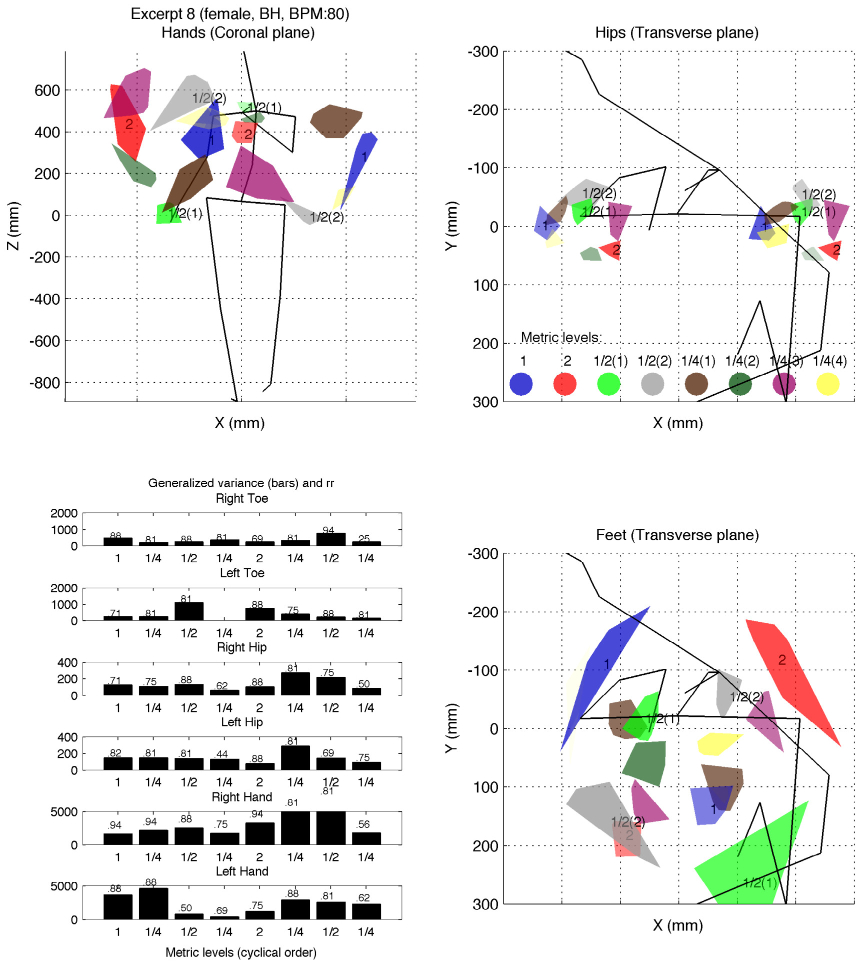


Figure 7.4: Representation of the topological abstractions for the excerpt 8 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topologies indicate the metric levels according to the model displayed in Figure 7.1.

peripersonal space (also seen in great part of the excerpts). The movements of the hips are performed in parallel (look at the similar disposition of metric levels): the first beat is marked on the left side (form the dancer's perspective) and second beat on the left side, contrametric levels are marked backwards, commetric levels are marked in forward movements (see excerpts 1, 4, 5, 7, 8, 11, 15, 18 and 23 for similar displays). Feet display more complex topologies. Each foot stresses the beat points by intercalating between frontward and backward positions. When one foot is positioned on the frontward beat positions (2-beat on the right foot, 1-beat on the left foot) the subsequent half-beat position (1/2(2)-beat on the right foot, 1/2(1)-beat on the left foot) is marked by a projection to the diagonal across a larger area (and high *rr*). At the same metric point, the other foot is projected towards the center of the intimate space. Other dance excerpts seem to mark beat points using lateral displacements (for example, excerpts 2, 3, 5, 11, 12, 14, 17, 18 and 24).

This panorama of topological regions shows the diversity of forms of occupation of space that dancers use in their choreography. Although the topological structure of the dances provides features that allow the development of forms of classification of the gestures, it would require further developments not realized in this study. Further research is needed in order to develop a methodology for the analysis and classification of the topological maps and topological relations depicted on the dance choreographies.

7.4 Basic gesture analysis of samba dances

7.4.1 Segmentation, processing and basic gesture representation

The basic gesture approach consists of (1) segmentation, (2) normalization, (3) principal component analysis (PCA) , (4) periodicity detection and a (5) representation of the gesture the three-dimensional space. Figure 7.5 shows a diagram of the processes.

First, the motion capture recordings (trajectories) were segmented in 16-beat sequences along with the musical annotation (beat and tatum time points and related categories of meter). Only the most homogeneous segment of the 16-beat sequences was selected and normalized (see the description of normalization processes in Section 7.2.1). Then, we applied a Principal Component Analysis (PCA) to each joint trajectory (3 dimensions/vectors) in order to determine the dimension (or coordinate) that captures the largest variance. In this dimension, we applied the periodicity analysis based on the algorithm *Any-Route* (see Chapter 4). This algorithm uses the metric levels of the musical meter as a sieve for searching for periodicities. The shape and periodicity of the periodic gesture was then reconstructed from the periodic bases provided by periodicity analysis, onto which musical cues could be projected.

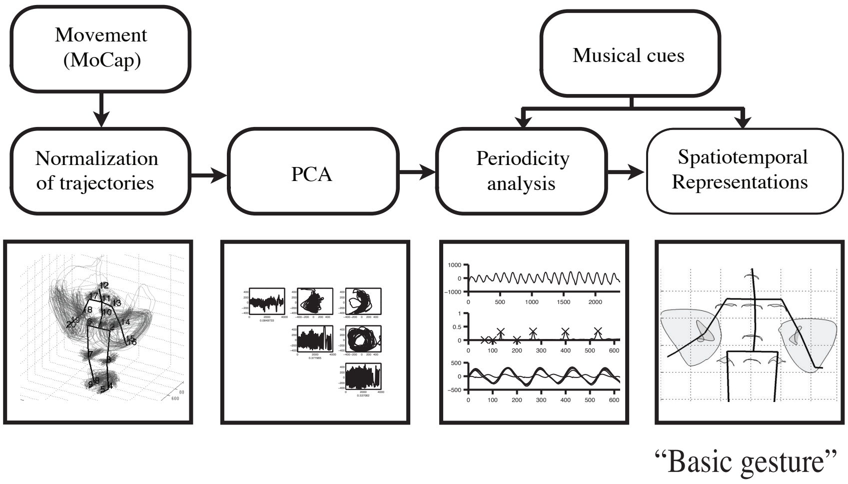


Figure 7.5: Schema of the processes involved in the calculation of the basic gesture forms. See Chapter 4 for a complete description of the method.

This process generates profiles of repetitive movements for each joint of the dancer in relation to each metric level of the music. For each metrical level, or each element of the metrical grid[3] there is one projection of the movement trajectories onto the *periodic space* (see example of these projections in different metric levels in Figure 4.7, Chapter 4). In this study, we will concentrate on the metrical level 2-beat, which corresponds to the main bar level of the samba music.

7.4.2 Overview and detailed view of basic gestures

Figure 7.6 displays an map of 16 basic gestures for excerpt 4. Figure 7.7 displays an example that resulted from a detailed analysis of the gestures for the same dance excerpt (see explanation in the captions). In order to provide a neat overview of the gestures, we excluded the wrist and ankle from the overview. In the detailed view, we described only a selection of ten joints: head (1), torso (1), hands (2), hips (2), knees (2) and feet (2). These two forms of visualization of results — overview and detailed view — are displayed in the Appendix B, for all excerpts.

The Figure 7.6 displays an example of the basic gestures of the dance excerpt 4. The bottom-left graph, second column, indicates the relevance of the periodicities

[3] In this study the metrical grid is composed of multiples and subdivisions of the beat composed of the following multiples: .25, .33, 5, .66, 1, 1.5, 2, 3, 4.

on each metric level. In this example, the periodic movement cycles are strong on the 2- and 4-beat levels. This means that the periodicities of these gestures are more pronounced in the periods of 2 and 4 beat length[4]. The shape of the gesture is also characterized by the level of variance in the eigenvectors (bottom-left graph, first column). For instance, the concentration of variances in one eigenvector observed in the elbows, shoulders and knees suggests that the movement of these body joints are performed in a "line-like", back-and-forth movement. The concentration of variances in more than one eigenvector in the hips, neck and mid-torso shows that there are more dimensions involved in the overall shape of these gestures.

The effect of the normalization (see Section 7.2.1) sheds light to the distribution of gestures around the dancer by excluding whole-body movements and retaining the movement profiles in relation the body of the dancer. Note that the transverse view (bottom-right graph) is specially informative about the domains of the gestures within the peripersonal space. In the Figure 7.7, we show the results of the detailed view for two gestures that were displayed in Figure 7.6. These representations are accompanied by points that indicate the metric position in the spatiotemporal representation at each .25 beat step.

Other interesting issues can be seen in other overview of basic gestures, displayed in the Appendix A. For instance, the excerpts 1, 13, 21 and 26 (pages 260, 284, 300 and 310) exhibit less periodic movements (see graph of periodicity transforms), which results in small shapes. This seem to be caused by improvisation choreographies (e.g., excerpt 1, 21 and 26, inspected in the motion capture recordings) or simple by a personal dance style that oscillates between synchrony and asynchrony with the meter (anisochrony). A special case of this diversity of the modes of synchrony with musical meter can be observed in the gestures of the excerpt 2 and excerpt 26 (pages 262 and 310). In these two examples the lower limbs exhibit strong periodicities that match the periods of the metric level while the upper limbs are not clearly synchronized with any of these levels[5]. Another case of non-symmetrical choreographic elements can be seen all over the detailed accounts of basic gesture curves: pairs of left-right gestures are very often dissimilar in shape (e.g., hands, excerpt 9 , page 277) but not so dissimilar in terms of level of periodicity and variance (eigenvectors). The basic gestures seem to exhibit less variability in the shapes of the joints that are close to the centroid of the body and more variability at the extremities of the body. More specifically, mid torso gestures and head gestures often take a form of a u- or 8-shaped gestures (e.g., excerpts 2 to 12, 14, 15, 17, 18, 22 to 24, 28 to 30, Appendix B).

Some dancers use a very simple gesture shapes that tend to be performed as

[4]The calculation of the ratio of energy extracted from the signal in different periodicities is only possible due to the non-orthogonality of the periodicity transforms (Sethares & Staley, 1999), used as basis for the *Any-Route* algorithm (Naveda & Leman, 2009).

[5]Curiously, dance excerpts 2 and 26, from SA choreographic background reported that their dance styles were rooted in their experiences with Afro-Brazilian cults.

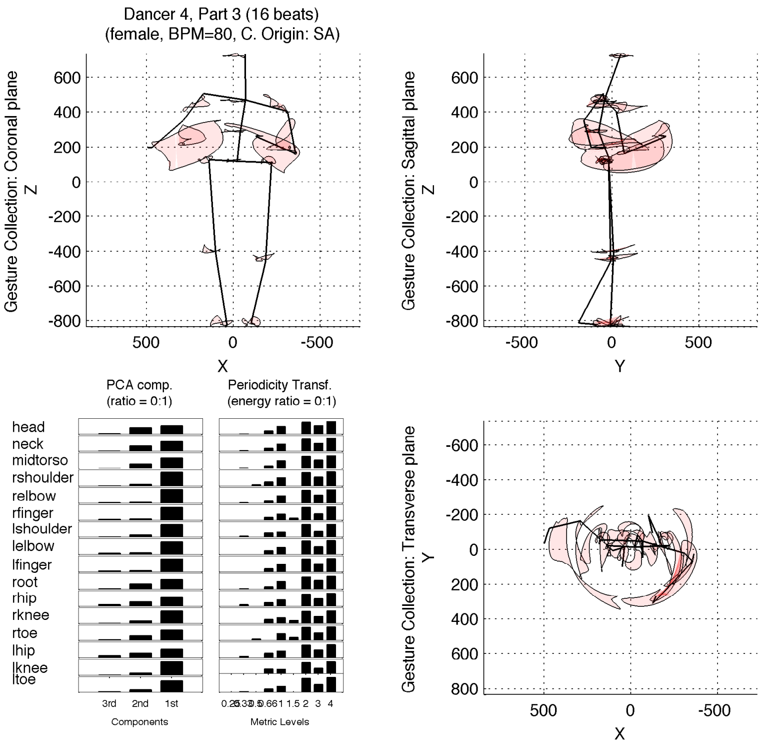


Figure 7.6: Overview of the basic gestures for the excerpt 4. In the first graph (top-left), the basic gestures are displayed in the coronal plane along with information about gender, choreographic origin and tempo (in beats-per-minute). In the second (top-right) and fourth (bottom-right) graphs, the same gestures are displayed in the sagittal and transverse planes. In the third figure (bottom-left), the first column displays the distribution of the variances across three eigenvectors (provided by the PCA). The second column displays the ratio between periodicities and signal (bars) for each metric level. They inform about the relevance of each metrical level in relation to each body joint.

a "line", such as dance excerpts 9, 29 and 30 (pages 277, 317 and 319); others exhibit more dimensionally complex movements such as the movements of hips, root and neck in the excerpts 3, 11 and 12 (pages 265, 281 and 283. This seem to be consistently reported by variances in the eigenvectors: line-like gestures are denoted by variances concentrated in one eigenvector, variances concentrated on two eigenvectors denote gestures performed as "planes" while evenly distributed variances across the three eigenvectors denote gestures with strong three dimensional components.

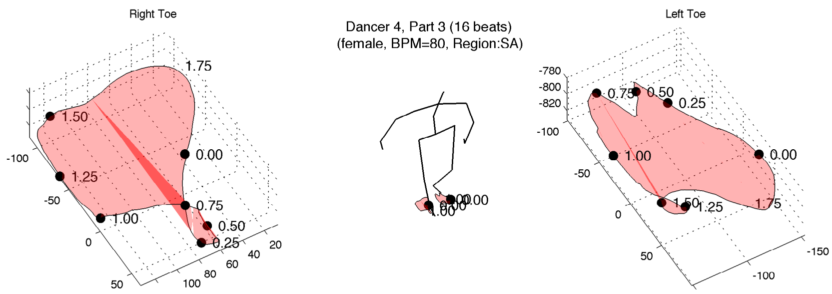


Figure 7.7: Detailed view of the dance gestures of the feet for excerpt 4, female, dancing at 80 BPM.

7.5 Classification of basic gestures analyses

Figure 7.8 shows the diagram of the processes involved in the classification of the gestures, which are based on the results of the basic gesture analysis. The classification consists of (1) Procrustes analysis, (2) weighted Procrustes body comparisons, (3) multidimensional scaling (MDS) and (4) discriminant analysis applied on MDS maps.

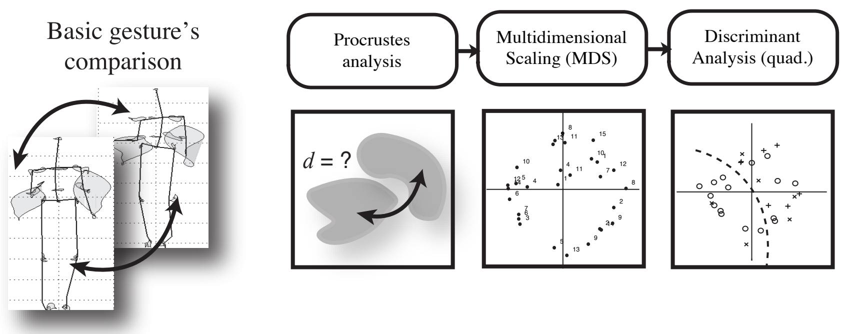


Figure 7.8: Process of classification of gestures. First, we measured the Procrustes distance between the gestures of each body joint. Then, multidimensional scaling algorithm (MDS) is fed with a weighted sum of the Procrustes distances, which results in a space where we tested the discrimination between gender, origin and tempo of the dance excerpts.

7.5.1 Procrustes analysis

The process of analysis of the basic gestures results in 20 three-dimensional representations of the basic gestures, encoded in 9 metrical levels for each dancer, from which we only processed the metrical level 2-beat. These spatiotemporal representations are not only geometrical shapes, but profiles of redundant movements, enriched with musical cues along spatiotemporal trajectories.

The points along the Basic gesture shapes offer an optimal combination of information about the gestural shape and features of the metric structure of the music. We use these points to compare the gestures of the dancers or more specifically to infer distances between the shapes of the gestures using *Procrustes* analysis. The Procrustes analysis is a form of statistical analysis that provides a measure of the distance between shapes after removing its rotational and scale components. It has been widely used in several fields such as gait studies (Wang et al., 2002), pattern recognition (McNeill & Vijayakumar, 2006) among others (see Goodall, 1991; Rohlf, 1999).

7.5.2 Weighted Procrustes body comparisons

The Procrustes analysis provides a metrics to compare shapes, but it is insensitive to the contributions of each gesture to the overall perception or performance of the choreography. A simple sum of all Procrustes distances between all the gestures of two dancers would give the same relevance for a large movement of the hand and a tiny movement of the head. However, several viewpoints on the notion of gesture, including psychological, bio-mechanical and musicological viewpoints suggest that gestures may have different magnitudes of perception (from both 1th and 3rd person perspectives). In order to derive a workable solution for the weighting factors of Procrustes distances we created a simple form of analyzing the gesture contribution that is based on the area occupied by the basic gesture, as explained below.

First, we applied the PCA to the three dimensional components of the basic gesture, which provides the best perspective of the variance of the 3-dimensional shape. In the sequence, we calculated the area occupied by the first two eigenvectors (two dimensions), which was divided by the sum of all areas of all gestures of the dancer. This gives a ratio of the area occupied by each gesture in relation to the area of all gestures of the body. Finally, the original Procrustes distance between two excerpts was multiplied by the mean of the ratios of the areas between the two excerpts. This generates the *weighted Procrustes distance*, which takes into consideration the magnitude of the gestures of one dancer compared with the gestures of another dancer. Other alternative solutions based on kinetic models or volumetrics could also provide good solutions but they were not tested in this study.

Figure 7.9 displays the profile of the ratios of the areas for all body joints. It shows that the area occupied by hands, followed by feet, are significantly larger in this data-set. It also indicates that the morphology of the body affects the morphology of the gesture: as the path of body morphology extends from central joints to extremities, the magnitude of the area of the gesture tends to increase. Note that the only exception is the head, which does not show a significant contribution to the magnitude of gesture movements but is considered an extremity of the human body.

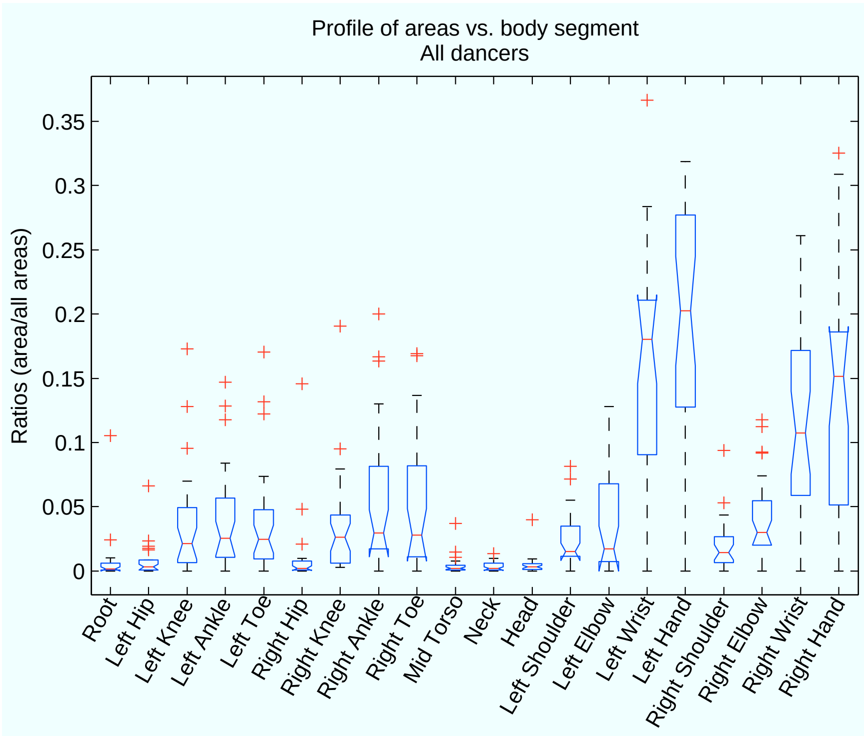


Figure 7.9: Ratio of the gesture areas formed by the two main eigenvectors of the gesture (after PCA) for each body joint. The ratio was calculated as the area divided by the sum of the areas of all body joints for each excerpt.

7.5.3 Multidimensional scaling (MDS)

The matrices of weighted Procrustes distances between all excerpts form a new "space". This space is not referenced by the 3-dimensional Euclidean geometry of space, but referenced by abstract distances (the Procrustes distances) between full-body choreographic gestures (all body parts). We used a multidimensional scaling algorithm (MDS) to relocate these distances in a new space defined by shape similarity. Therefore, for each pair of dances, the sum of the weighted

Procrustes distances was organized in a dissimilarity matrix and processed in a multidimensional scaling algorithm (MDS). The test of goodness-of-fit, displayed in Figure 7.10a, shows that the MDS solution for 3 dimensions displays good linear results[6]. The choice for 3 dimensions resulted in an acceptable stress factor, as displayed in Figure 7.10b.

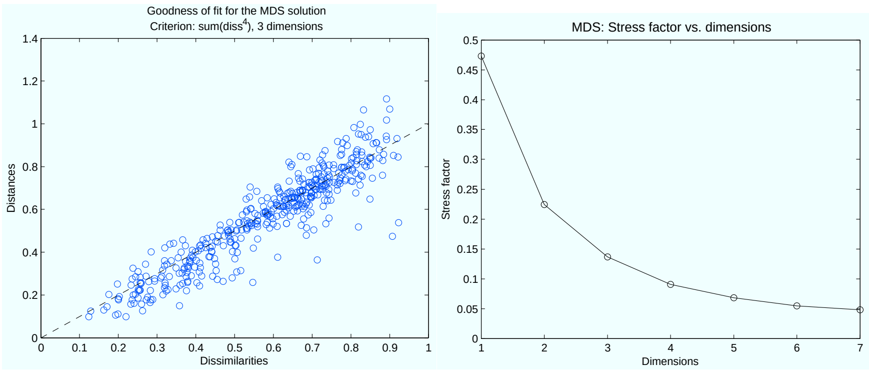


Figure 7.10: (Left) Goodness-of-fit between distances and dissimilarities. For the metric scaling we used the criterion of squared stress, normalized with the sum of the 4^{th} powers of the dissimilarities. (Right) Profile of the stress factor for 1 to 7 dimensions.

The relation between stress factor and dimensionality displayed in curve in Figure 7.10b can be used as a measure of the complexity of the morphology of the gestures. Highly complex shapes of gestures would require larger dimensional solutions from the MDS algorithm. The stabilization in small stress factors along dimensional solutions indicate when minimal dimensional solutions are achieved. In Figure 7.11, we display curves of stress factors for the Procrustes distances between gestures, which were calculated between the same joints, for five dimensional solutions (3 to 8 dimensions). The aim of this process is to indicate the level of complexity of the group of gesture shapes for each body joint.

The information displayed in Figure 7.11 indicates that gestures of the hips and knees show more complex morphological spaces in this data-set, followed by head, torso and right ankle, right shoulder and right toe. Hands and segments more directly connected with the hands show less complexity. These measurements do not indicate the complexity of the shape itself but the complexity in finding dimensionality solutions for similarity between these gestures. Higher stress may also indicate higher variability in shape, noise or problems in the measurements. It was expected that joints (root, torso) that occupy small volumes would be more

[6] For the metric scaling of the MDS method, we used the criterion of squared stress, normalized with the sum of the 4^{th} powers of the dissimilarities.

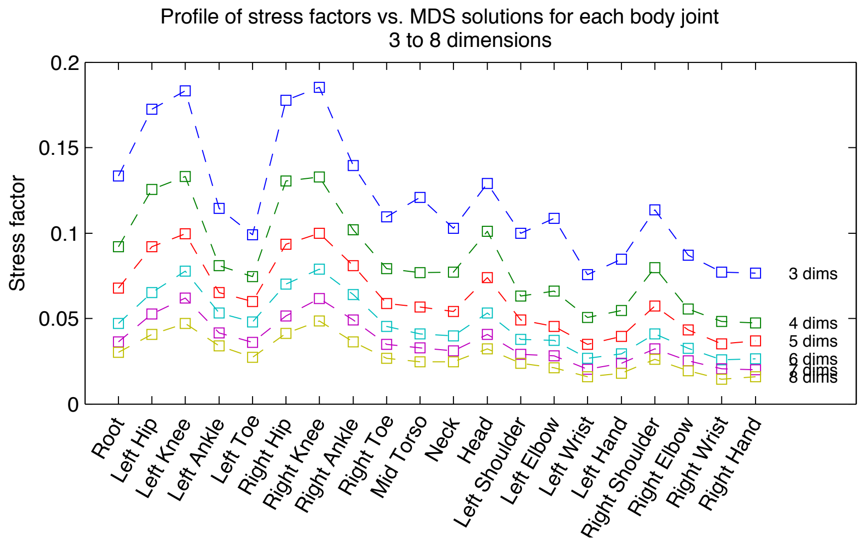


Figure 7.11: Profile of relation between stress curves of the MDS solutions and each body joint, processed from the Procrustes distances in 6 MDS solutions (3 to 8 dimensions).

subjected to measurement bias but strong personal idiosyncrasies could also explain the higher complexity.

7.5.4 Discriminant analysis applied to MDS maps

The MDS allows for the organization of the gestures of all dance excerpts in a 3-dimensional representation, displayed in Figure 7.12. This map of distances define a kind of "morphological space of the choreography" because it reflects the similarity of the shapes (morphologies) between excerpts. The stress factor resulted from this configuration is relatively low (stress f. = 0.14), which guarantees a good representation of the data-set. But how the characteristics of the dancers and dance excerpts are reflected in this map? Do the differences between shapes of the gestures reflect the differences between gender, choreographic background or tempo of the dances? What are the dances and gestures that better characterize the collection of dance excerpts and the characteristics of the dancers?

We conducted a discriminant test, based on quadratic discriminant analysis (QDA) (see Jain et al., 2000, for further information), which responds to some of the these questions. This process consisted in classifying the points of the distribution provided by the MDS with different characteristics of the dances and dancers. The QDA discriminates categories of data points by tracing a quadratic decision boundary between the points (e.g., an ellipsoid or a paraboloid). Points that are classified incorrectly are considered errors or non-predicted points. In short, this classification provides a rough measure of how much a class (e.g., male, female, fast or slow choreography) is recognized/discriminated by the shape of the dance gesture.

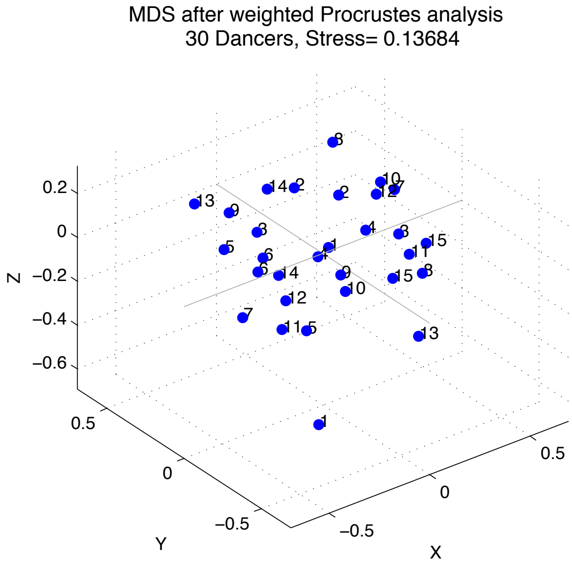


Figure 7.12: Three dimensional representation of the weighted Procrustes distances for all excerpts (1-30, numbers represent excerpts), after multidimensional scaling. The next figures will be displayed in a two-dimensional perspective in order to simplify the visualization. The MDS map will still keep its three-dimensional structure.

7.5.5 Results of the discriminant analysis (QDA)

Choreographic origin Figure 7.13 displays the result of the discriminant analysis for the classes of choreographic background or origin, indicated here as BH (Belo Horizonte) and SA (Salvador) labels. As described in Section 7.2.2, the origin of the dancers is supposed to assume different choreographical matrices of Samba dance styles.

The information of medoids[7] and poles[8] displayed in Figure 7.13 shows the characteristics of the dancers (d1 to d15), which designates the subject that per-

[7]Medoids are representative objects of a data set or a cluster whose average dissimilarity to all the objects in the cluster is minimal.

[8]Poles are pairs of objects that exhibit the maximum distance between each other in the data set.

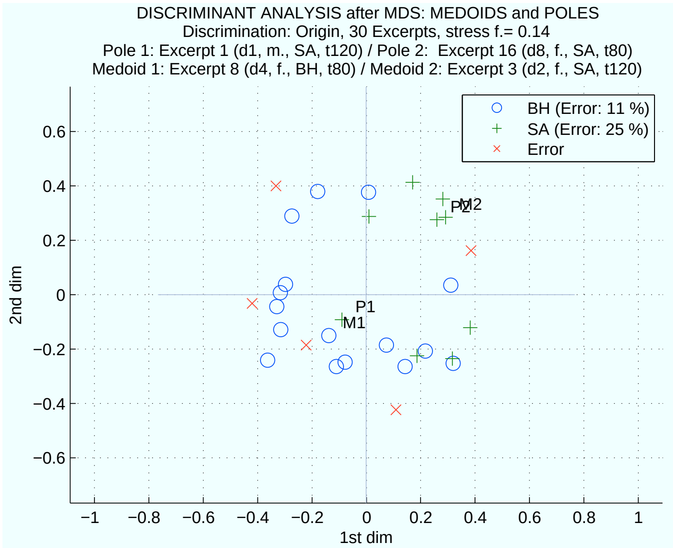


Figure 7.13: Results of the discriminant analysis using the original division between choreographic background/origin. The visualization was simplified in two dimensions.

formed the dance, his/her gender (m. or f.), choreographic background (BH or SA) and the tempo of the dance (t80 for BPM=80 and t120 for BPM=120).

The percentage of errors in the classification (excerpts incorrectly classified are indicated by "x" markers, or "errors") denotes the level of discrimination of each class. The large error (25%) of the SA class (representing the *Bahian* choreographic matrix) indicates that the gesture shapes of the dances from SA were not easily classified by their similarities. The largest distance between choreographies (pole 1 and pole 2) was found between elements of the SA choreographies (see gestures of the excerpt 1 and 16, on pages 260 and 290). The choreographies from the BH origin seem to be more discriminated, compacted in the choreographical space and exhibited a very small error.

The medoids M1 and M2 (excerpts 8 - BH and 3 - SA, see pages 274 and 264) represent the choreographies that have the smallest distances to the mean of all elements within the discriminated class. They represent the closest renditions of the "choreographical model" of BH and SA styles. Obviously, it does not mean that they represent the samba style for these groups but they provide a cue about the possible frames of reference used by these dancers at the moment of the recording. A close inspection in the detailed view of the gestures unravel other characteristics, displayed in Figures 7.14 and 7.15. Note that the gestures of the hand in the BH medoid are larger and exhibit more circular movements, while the ones of the SA style exhibit more direct trajectories between first and second beat points. In the feet's gestures, the SA style is characterized by larger movements that use the lateral sides of the gesture (left-right) as beat points. On the contrary, the feet on the BH style are projected back and forward between beat markers.

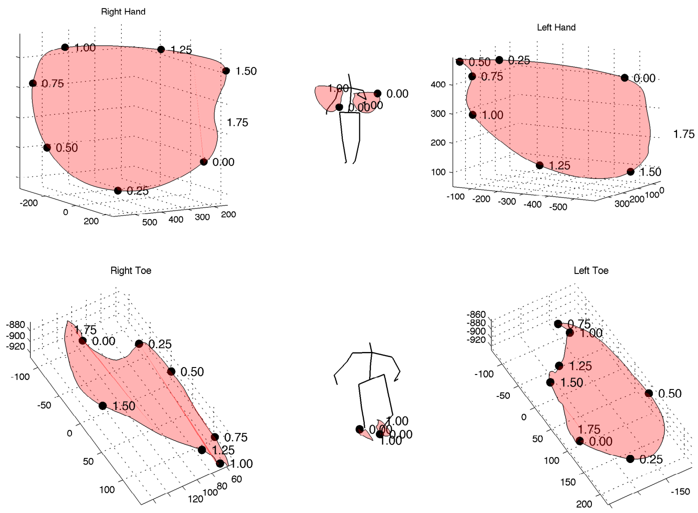


Figure 7.14: Details of the hand and feet gestures for the Medoid representing the BH style.

Gender Figure 7.16 displays the result of the QDA for the genre classes: male and female dancers. The results show less errors in the discrimination. The most dissimilar pair of choreography is characterized by a male-female pair (excerpts 1 and 16), dancing at 80 and 120 BPM in SA style, which reinforces the apparent variability of the SA style, observed in the last section. The medoids indicate that the models for male and female reside in the BH style, at 120 BPM. The shapes of the medoid of the male class (excerpt 29) are displayed on page 316 while the shapes of the medoid of the female class (excerpt 18) are displayed on page 294.

The most clear difference between gestures of male and female represented by the medoids relates to the tendency to rounded gestural shapes of female gestures, and a tendency towards more direct, line-like shapes of the male gestures. This information can be easily accessed in the graphs of variance (displayed in the bottom-right figures, pages 316 and 294, male and female gestures respectively).

Tempo Finally, Figure 7.17 shows the discriminant analysis for the tempo classes, which convey the dances accompanied by music sequences with tempo adjusted to 80 and 120 beats-per-minute (BPM). There is a very small difference between

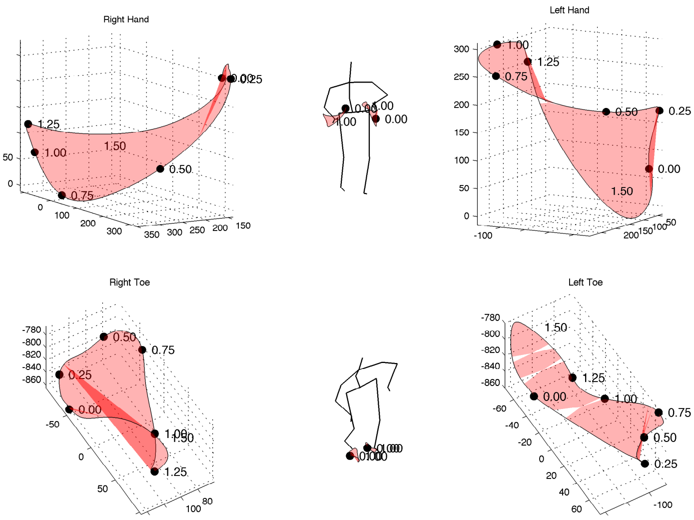


Figure 7.15: Details of the hand and feet gestures for the Medoid representing the SA style.

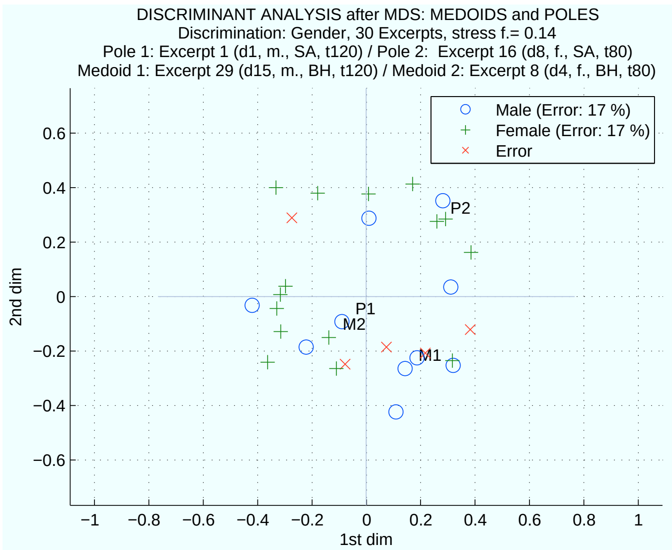


Figure 7.16: Results of the discriminant analysis using the original classes male and female in the gender comparison. The visualization was simplified in two dimensions.

errors in the tempo classes and the largest differences (poles) reside in two instances of male dancers in the SA style. The medoids are found in female dancers from BH style, at 80 and 120 BPM. The gestures of the dancer in medoid 1 are displayed on page 314 and the gestures of the dancer in the medoid 2 are displayed on page 274, Appendix B. The errors displayed in these two classes exceed the errors of other discriminations (31% for BPM = 80 and 29% for BPM = 120) and no apparent dissimilarities were found in the characteristics of the gestures of the medoids. The gestures of dance excerpt 8 (medoid of BPM=80) seem to be slightly more rounded than the excerpt 27. It was expected that fast gestures would exhibit streamlined shapes, which is not represented in our medoids.

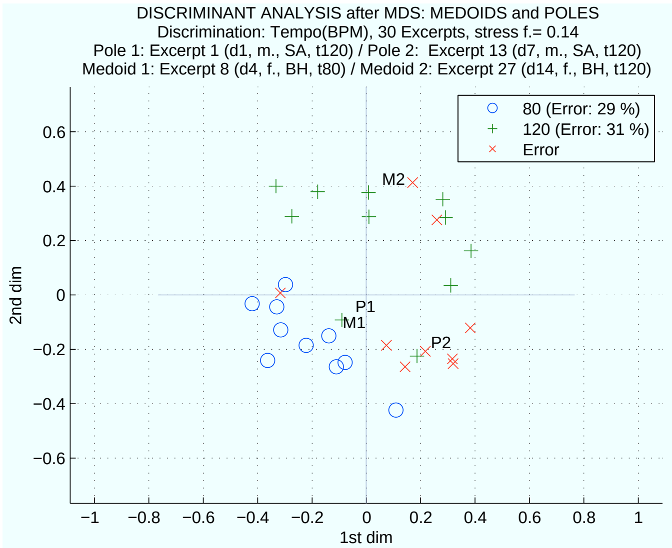


Figure 7.17: Results of the discriminant analysis using the original division between tempo classes. The visualization was simplified in two dimensions.

7.6 General discussion

In this study, we investigated several characteristics of the gestures in samba dances: relations with musical meter, general tendencies related to gender, tempo and choreographic backgrounds. The methods applied here provide gesture-specific, subject-specific and data-set specific analyses of the relation between meter and gesture in samba dance. These representations may indicate the characteristics of the reference frames through which dancers enact the style. The reference frames are rendered here from the viewpoint of *shapes* and *topologies*.

In the dancer- and gesture-specific overviews of gestures (displayed in the Appendices B and A) we presented “maps” of basic gestures and topologies for each dance excerpt. The differences between the results of the two methodological approaches reflect the way they process information. In the heuristics of the basic gesture approach the shape of the gesture is emphasized. The variability in space takes a secondary place in favor of the focus on periodicity of the gesture trajectories. Even if the movement lacks periodicity, the algorithm will attempt to find the best periodic shape possible in the signal. However, the amplitude of the shape and the ratio of energy of the gesture will be negatively affected. In the TGA approach, variability takes a primary role. If there is a region repeatedly used to perform one category of musical cue (e.g., a gesture on the 1^{th} beat) it does not necessarily need to be periodic in order to be captured as a large region in space, it only needs to be redundant in space. Periodicity will positively affect the ratio of recognition and the shape of the gesture will change the position of the topologies in space.

The Figure 7.18 demonstrates two examples where these differences are clear. In the first row, a marginally periodic performance renders tiny curves of basic gestures (metric level 2-beat) for excerpt 1. The lack of periodicity decreases the magnitude of the basic gesture but the original trajectories exhibit large movements. These non-periodic and large movements are reflected in large topologies shown in the top-right figure, using TGA. The lack of periodicity smear the ratio of recognition of the topologies, denoted by the the level of transparency of the convex hulls. In the second row, the performance exhibit a strong periodicity in the basic gesture (see also variance and energy measures on page 274), which is translated in strong ratios of recognition (less transparency) in the TGA figure. In summary, the basic gesture approach reveals periodicity of the gesture trajectories, the TGA approach reveals variability and redundancy of the gesture space.

The classification of BG gestures revealed similarities and dissimilarities between the dancers’ choreographies. The following summary stresses the main aspects found in the process of classification.

Morphology and complexity of the gesture The controlled environment of the tasks stipulated in this experiment was not sufficient to cope with the tendencies of improvisation, asynchrony and anisochrony verified in the dances. Dancers exhibit tendencies that range from strong synchronization with metrical cues to the complete absence of synchronization with meter. In several profiles of gestures, dancers were able synchronize parts of the body with the meter or oscillate between synchrony and asynchrony with the musical meter. The gestures seem to form one- or two-dimensional shapes (“line” or “plane”) and rarely exhibit uniform variances in three dimensions (“volume”). As the gestures spread from torso to any of the extremities (excepting the head), the shape of the gestures tends to increase in magnitude, variability and use of space. Conversely, the similarity between gestures

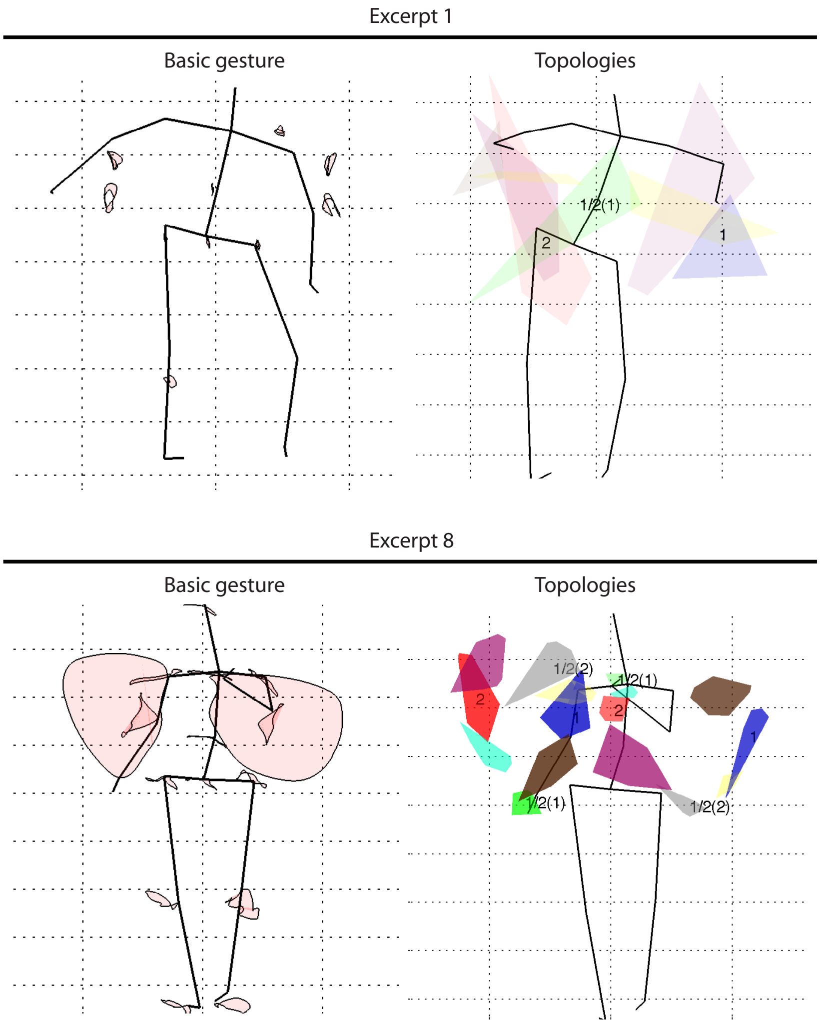


Figure 7.18: Basic gesture and TGA analyses of excerpt 1 and excerpt 8. Although these methodologies complement each other in different aspects, the basic gesture and TGA approaches offer very different explanations for the gesture (see text for explanations).

close to the torso shows more complexity as seen from a Procrustes distance viewpoint.

Choreographic background The excerpts from the SA background exhibit more variability from the perspective of the shape of the gestures. Dancers from the BH class use less space and are more similar between each other. Feet gestures of the excerpts from the SA class seem to use more the lateral extremities to mark beat points (1- and 2-beat levels), excerpts from the BH class seem to use more streamlined gestures projected backwards and forwards.

Gender differences Female dancers, in special from the BH background exhibit more circular gestures with beat regions more dispersed than the male ones. Some female dancers tend to exhibit gestures that are more complex in three dimensions. Male dancers seem to dance using more direct and streamlined gestures.

Tempo and meter Surprisingly, tempo differences are not so pronounced. The higher error of discrimination indicates that the classes are entangled, which means that the gestures danced in slow and fast tempi are not so dissimilar from the perspective of the methods used in this study. Gestures performed in slow tempo (BPM=80) seem to be more rounded and occupy more space but but these results are not clearly defined.

7.7 Conclusion

The attempt to define what are the fundamental components of samba dance probably represents an intractable task from computational, cognitive and ethnographic viewpoints. The panorama of individual renditions of samba dances here displayed demonstrates that the “fundamental” elements of the samba dances style are translated by embodied, tacit and explicit knowledge in a large spectrum of gestural models and modes. Samba dances seem to combine not only models of postures, gestures or repetitive movements but also a diversity of modes of entrainment with meter, dialogs with group and individual idiosyncrasies and other influences. Although we are tempted to indicate a “model” that defines the samba dances in our universe of research (and although such task would not require large computational resources) we cannot avoid the insignificance of single choices or models in our universe of dances. We thereby argue that samba dances may not be significantly represented by a single repetitive dance form, not even represented by a fixed style of movements. Samba dances seem to be strongly characterized by relationships of affirmation of musical meter portrayed on the foreground of ambiguous metric relations in samba music. These tendencies are rendered through a large panorama of gestures such as the portrayal exhibited in this study and they may be induced by necessity of selecting forms of choreography that cope with the ambiguous background of meter in samba music.

Acknowledgements

We would like to thank all the dancers that participated in this study. We are thankful to Prof. Dr. Maurício Loureiro (UFMG, Brazil), Prof. Dr. Ivani Santana (UFBA, Brazil) and their students for the support to our experiments in Belo Horizonte and Salvador (Brazil).

7.8 Complementary study: Metric periodicities in movement and sound

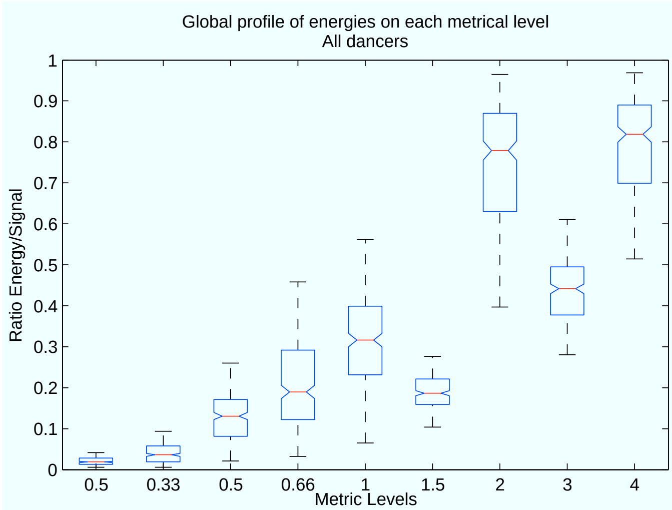
In the Sections 1.3 we have discussed the the role rhythmic and metric ambiguity in the interdependency of dance and music forms in samba. During the experiments with few movement and music sequences reported in Chapter 3, Section 3.8.2.2, we suggested that metric ambiguity could be verified in the profile of periodicities of music and dance. In the complementary study reported here, we analyzed all the movement profiles of the motion capture recordings analyzed in the main experiment using the same methodology suggested in the Chapter 3.

The methodology consists in collecting all the ratios of energy of the periodicities in all body joints for all dancers. These measures of energy were calculated as the ratio of energy (norm) extracted from the signal by the periodicities, which was processed by the *Any-Route* algorithm during the calculation of the basic gestures (see Chapter 4 for more information).

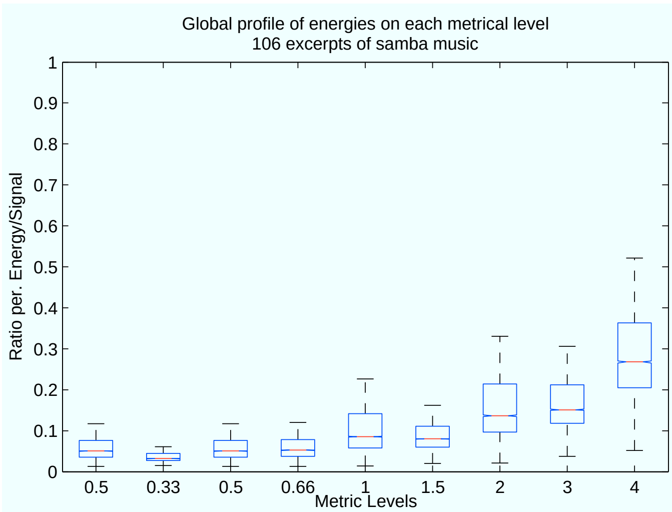
The graph displayed in Figure 7.19a displays the mean of all ratios of energy of the meter-related periodicities. It basically indicates the relative importance of periodicities of musical meter on each gesture. Since the measurements are taken from a non-orthogonal decomposition of periodicities, beat level 2-beat may contain energy from metric level 1-beat and metrical level 4-beat may also contain energy from metric levels 1- and 2-beat. The intrinsic ambiguity of the metrical information do not deny the strong tendency to binary metrical structures in the dance gestures.

The same process of periodicity analysis was realized in the audio domain, in Section 6.7, using exactly the same algorithm. The process was applied to loudness curves generated by an auditory model (44 auditory channels) in a data-set of samba music (106 excerpts, divided in 281 parts with 16-beat length). The results are represented here in Figure 7.19b for comparison. Note that although the distributions are skewed, binary periodicities are not as pronounced as ternary and quaternary periodicities and remain close to 1-beat and 1.5-beat periodicities.

The analysis of periodicities in the movement profiles confirm a strong binary tendency of dances (2- and 4 beat levels), already suggested in former studies (e.g, Section 3.8.2.2). The combination of the results of the movement periodicities with results of the same analysis applied to music (described in Section 6.7) suggests that the metrical ambiguity of samba music is complemented by or dependent on the metrical clarity of dance forms. The impact of these observations will be discussed in the Section 7.6.



(a) Periodicities in the data-set of dance.



(b) Periodicities in the data-set of music excerpts.

Figure 7.19: (a) Profile of the means of the ratio of energy in the metric levels for movement periodicities (all segments and dancers, $F(8, 2295) = 752.3587, p < 0$). (b) Profile of the means of the ratio of energy in the metric levels for auditory periodicities (44 channels x 106 excerpts of samba music, $F(8, 74044) = 6696.3433, p < 0$.

8 General discussion and Conclusion

8.1 Overview

In the introduction of this work, we have demonstrated the necessity for more comprehensive approaches to the embodied aspects of Afro-Brazilian, in which we include music and dance. More hypotheses and explanations are particularly needed in order to understand how the coupled nature of music and dance are realized by means of corporeal articulations of dancers and musicians. We have illustrated how a disembodied notion of knowledge has been imported from a Western viewpoint into the lineage of Afro-Brazilian music and dance styles. A selection of “pure” musical texts (certainly detached from its social and musical attachments to dance) still supports the main explanations for the emergence of modern samba. We delineated our main hypotheses from several questions raised in the social and historical panorama of Afro-Brazilian music forms. Why are Afro-Brazilian music forms always linked with dances? Why is such a musical culture systematically characterized as syncopated and frequently connected with “movements” of the body? Which kind of movements account for these dances? How are they connected with music?

In the course of this research, we found an elaborated literature on the relations of samba with the Afro-Brazilian culture but few accounts on how this human body, movements and forms of enactment are related to the samba culture. We have found consistent reports on how samba music is structured and performed but few accounts on the relationship between music and dance in social display. Our main challenge was to give accounts of dance gestures in samba that inform about the relationship with musical features. These accounts were based on cross-modal methods, which afford the analysis of the cross-modal gesture with methods that preserve the musical-choreographic structure.

We have argued that methodological demands in the analysis of gesture in dance and music were determined by experimental, algorithmic and representational demands, which were not entirely explored in the literature. We have gradually approached these demands, by discussing an extensive review of the literature (Chapter 2), by elaborating on novel methods and processing techniques (Chapters 3, 4, 5 and 6) and by analyzing data-sets of music (Chapter 6) and dance (Chapter 7).

In the Chapter 3, we introduced a computational heuristic that combined metrical information from music to uncover patterns in dance gestures. Instead of looking at movement as a hermetic system or searching for single responses or parameters, we used a method (Periodicity Transforms) that uncovered a set of solutions for the gesture periodicities based on the interaction of movement with musical meter. By rejecting single parameters and single modalities and by considering summaries of the relationships between music and dance we incorporated the tacit and explicit knowledge of dancers and musicians into the development of computational heuristics. The study presented in Chapter 3 demonstrated that epistemology and culturally-specific characteristics found in the literature could be used to design better algorithms. From a epistemological perspective, this transformation from cultural abstractions (relationship between dance and music) into numerical processes (algorithms that take into account sound and movement) recall the structure of the multilayered framework[1] proposed by Camurri et al. (2001). In other words, it replicates the transformation of information from high- to low-level levels in the network, regarding methods: it transforms concepts in epistemology into changes realized in the signal processing.

In Chapter 4 we expanded the epistemological and experimental scope of Chapter 3 and improved the framework of the heuristics for pattern detection. In this Chapter, we analyzed different styles of popular dances (samba and Charleston) and different levels of expertise (teachers and students) by means of an improved version of the original algorithm introduced in Chapter 3. We applied these developments to motion capture data and experimented with new representations that gave rise to the concept of *basic gesture*. The *basic gesture* is a concept that was detached from the numerical method proposed in Chapter 3 and enriched with an epistemological background on cognition and embodiment. The idea behind the basic gesture approach is that it conveys a spatiotemporal reference frame on which dancers base their choreography. It can be seen as a form of mental representation, or as an imprint in the motor domains that is activated and dynamically transformed in the process of the rendition of gesture. Basic gestures are assumed to be formed by

[1] See page 15

the incorporation of action-perception couplings between music and movement, or music and dance. This work on basic gestures formed the starting point for the development of the main conceptual elements that were used and complemented in further studies (e.g., Chapters 5 and 7).

The *Topological Gesture Analysis* (TGA), introduced in Chapter 5, involves a sort of antithesis to the conceptual and methodological background represented in Chapters 3 and 4 and to the concept of *basic gesture*. The topological representations convey a form of analysis abstracted from shapes, distances or coordinates. It focuses on qualitative relationships and reasoning between music and space and between regions occupied by the gestures. We used this alternative geometry to qualify the space with meter-related musical information, which provided a topological map of the organization of the peripersonal space in relation to musical meter. Moreover, the TGA approach collects the variability in the trajectories re-presents it as topological geometry. It assumes novel forms of interpreting gesture from topological relations and contributes to an additional set of cross-modal algorithms. The methods displayed in Chapter 5 are based on the same data set discussed in Chapter 4, which provides a comparative basis for understanding these two complementary ways of representation.

Up to this point, we have focused on providing responses to problems of representation of the gesture (specified in Section 1.5.3). In the musical domain, a profuse bibliography in the field of samba music had already contributed to the basic musical assumptions that supported the research in gesture (e.g., rhythmic priority of samba music, connections of samba with African roots and its metric characteristics). However, other "movement inducing" characteristics attached to samba music become latent in the framework of research. Issues such as *groove* induction, polymetric content, periodicity in the auditory domain and entrainment of rhythmic structures became particularly important due to the lack of scientific accounts and supporting experiments in the literature.

In Chapter 6, we explored a number of these issues related to the microtiming samba. In the first study, we investigated the patterns of microtiming deviations collected from a data-set of 106 excerpts of commercial samba music. We analyzed how pattens of microtiming interact with the meter, spectrum and intensity in the auditory domain. In the first complementary study, we applied the same methodology to spontaneous vocalizations of samba rhythms recorded from musicians and non-musicians. In both experiments, we verified the same consistent profile of "deviations" and other tendencies of metric induction. Although these experiments marginally contributed to the main notion of embodiment, they unravel a deeper layer of rhythmic/timing ambiguity, which cannot be derived from symbolic interpretations of the sonic "texts" (e.g., scores). In the second complementary study, we reapplied the methods for periodicity detection reported in Chapter 3 to computational analyses of musical audio. These results report on the ambiguous nature of the periodicities in samba music, which were juxtaposed with the same analysis in the movement domain, in Chapter 7 (Section 7.8).

In Chapter 7, we applied the methods developed in the previous chapters to a larger corpus of samba dances. We studied the characteristics of gestures of samba dances and how dances are affected by gender, tempo and choreographic background. The experiment involved the recording of 30 dance excerpts recorded with professional samba dancers and was processed using basic gesture and TGA approaches. It resulted in a panorama of detailed analysis of dances represented as gestural shapes and topologies. These analyses were further correlated and discriminated using a number of methodologies, which provided a set of global tendencies and models of choreographies defined by the discrimination between gender, tempo and choreographic background differences. The results of this chapter contribute to enriching the knowledge of dance and music forms of Afro-Brazilian culture by introducing novel methodologies, questions and findings not envisaged in the previous literature.

8.2 General discussion

The rich panorama of gestures that was obtained in Chapter 7 overshadowed the tendencies to define single models for samba dances. The relationships between dance gestures and music found in this panorama reinforced the idea that samba dances are not represented by a single gesture shapes nor by a single paradigmatic notion of choreographies. The structure of samba dances seem to be rooted in a constant affirmation of "musical" meter that is dependent on the ambiguous metric relations in samba music. From this perspective, meter appears to be much more a choreographic feature than a musical one. If one looks at the representation of meter in dance, its structure seems to be more detailed and contains more parallel levels than the representation in music. Sub-categories of metric levels populate the space of dance, which are signalized through topologies of sub-levels of meter or vertices in the basic gesture shapes.

So far, the notion of style in samba dances may be highly influenced by subtle relationships encoded in the finer structure of the gestures: patterns of accelerations of the trajectories, dispersion of the topological structure of dance (e.g., as discussed in Section 5.3.3) and specific modes of coordination between joint movements. These fine-grained kinematic characteristics resemble what microtiming structures found in samba music represent to timing in music (as discussed in Chapter 6): a kind "expressive kinematics" of the dance gestures that may be translated into the sensation of idiomatic performance, or simply *style*. The study of these subtle characteristics is beyond the scope of the methods we proposed in this work but should be taken in consideration in future studies

Finally, the relationship between music and dance in samba seem to be regulated by a symbiotic relationship. While the two forms exhibit different metric structures (see Figures 7.19) and different renditions at low-level information (e.g., see panorama of gestures in the Appendices A and B) their interaction benefit from each other as a system of cultural concepts (high-level). We have argued that ambiguity in the music domain depends on clear metrical structure in dance. Ambiguity in music has been denoted by a focus on contrametricity and a lack of dominant commetric periodicities (see Section 2.3.1), concurrent periodicity levels in the acoustic domain and ambiguity in the form of microtiming deviations (see Chapter 6). The predominance of the binary metric structure in dance has been denoted by the structure of the shape of the dance gestures (see Section 7.4), the periodicities in the kinematic descriptors (see Section 7.8) and the clear recognition of commetric topologies in dance display (see Appendix A). The equilibrium between ambiguous and unambiguous content seem to avoid both alienation (excess of ambiguous content) or monotony (excess of unambiguous content), in the context.

The approach to samba described here influences the way we look at the development of music and dance forms in samba in several respects. It indirectly implies that every dissociation of music from the social display of dances in Afro-Brazilian culture would require less ambiguous rhythmic structures in music. From another perspective, a close link between music context and dance forms would require or permit more musical contrametricity and less attachment to metrical rules. Such a compensation mechanism could offer a number of possible explanations for several socio-historical aspects of the samba. For example, the connection of "syncopation" with the idea of African origins could be reinforced by the necessity of dance displays, always connected with the social environment of Afro-Brazilian traditions. The appropriation of the *surdo* instrument (commetric) during the dissemination of samba on the radio in the 1930s could be explained by the necessity to compensate the lack of dance displays (imagery and social context) not present in the radio communication. The incorporation of commetric beat-lines in sub-styles that do not exhibit clear dance signatures such as the "samba-rock" or the "bossa-nova" could be also studied from this hypothesis.

Epistemological premises

Although the contributions of the present study have a direct impact on the musicological questions of Afro-Brazilian samba, we also envisaged a set of contributions to the epistemology. The contributions are described here as a set of premises that were forged in the course of our research but are potentially extensible to other cross-modal contexts: (1) the premise of *layered content*, (2) the premise of *cross-modality*, (3) the premise of *complementarity* and (4) the premise of *variability*. These premises are illustrated in the Figure 8.1 and described below.

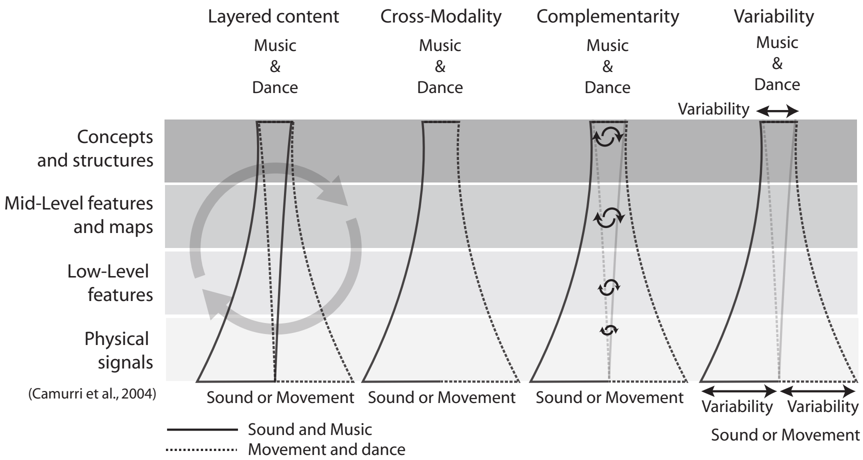


Figure 8.1: Four premises of cross modality, organized on the foreground of the multilayered framework proposed in Camurri et al. (2004).

Premise of layered content The premise of *layered content* deals with the transit of information in the multimodal network, as proposed in Camurri et al. (2004), described in Section 1.4.2 (Figure 1.1). It maps how movement and sound carry information that forms "culture" (bottom-up flow) and how culture deploys meaning in sounds and movements (top-down flow). The transformation between low-level data (e.g., sound, movement, timing) and high-level structures (e.g., symbols, emotion, styles) forms the fundamental exercise that allows for observing connections between dance and music, meaning and actions.

Cross-modality The premise of *cross-modality* implies that dance and music are considered as *modes* of the same gestural intentionality and therefore, at certain levels of information, could be subjected to the same methodological approaches. This perspective led to the development of a series of cross-modal methods such the framework of basic gesture (Chapter 4) and TGA (Chapter 5). The use of cross-modal methods to analyze cross-modal cultural phenomenon improves results and consistency of the analysis.

Complementarity The premise of *complementarity* relates to the unity or interdependence of modalities in the multimodal network. It implies that the modalities are not only connected by a network structural correlations (isomorphic) but are also connected by structural dissimilarities through which they share information and become mutually dependent. This premise supports the hypothesis that metrical ambiguity in music is complementary to the metrical affirmation in dance.

Variability The premise of *variability* of cross-modal forms arises from observations in ethnographic and movement studies. A number of studies in these fields indicate that the forms of deployment of dance gestures and music are much more variable than the cultural and social concepts that unify them. It implies that concepts such as styles of music, emotions or perceived expressivity in gesture forms are coherent at higher levels (conceptual level) but that their renditions as musical patterns, gestures, patterns of movement and rhythm characteristics are often incoherent between their peer elements at lower levels (level of signal). Gestural characteristics are perceived and "labeled" at a higher level in the multimodal layered framework but their classes may not be easily recognized in low-level data. In this perspective, a small number of low-level instances informs about the high-level levels of information, but these instances may not appear similar to other instances at the same level of information.

Since these premises only serve as background knowledge for the research, their level of generality are unknown outside the specific domains of the Afro-Brazilian culture and the relations between the dance and music manifestations of samba. However, we see indications that the generality of this model may be extended to other dance-music ecologies or contexts were divisions between modalities are not entirely clear at higher levels of cultural abstraction.

8.3 Conclusion

In this thesis, we focused on the relationships between music and dance in Afro-Brazilian samba. Some of the challenges faced in the course of the studies were surpassed through novel methodologies. Other challenges remodeled the questions we have raised and reshaped our view on the samba culture. Our contributions are then distributed in the form of methods for the analysis of dance and music, perspectives on the culture of samba and panoramas of gesture descriptions. The next topics summarize the main contributions of our work.

Cross-modal study of gesture The systematic integration of modalities in all stages of investigation, from the epistemological basis to the algorithm design, represents a relevant contribution to the framework of the research in gesture. Although the concepts and methodologies envisaged by the basic gesture and TGA approaches are not perfect, closed or extensively validated, they offer a well-formed example of dialog between premises of the universe of study and premises of the methods. This could only be possible by means of a broad review of literature and a strong effort in processing subjective information into computer modeling techniques.

Musicology and dance The panorama of methods in ethnomusicological and musicological disciplines have been extended to the domains of dance research. By considering the functions of music, its structure and context described in the literature, we were moved to investigate a domain that is external to the music itself: the domain of movement and the culture of dances. We contributed to the paradigm of systematic musicology by considering music from the perspective of the dance. By looking at music in relation to dance and vice-versa we envisaged new structures of music, novel structures of meter, different forms to understand commetricity and contrametricity. We detected new layers of rhythmic tension, new forms of expressive timing and demonstrated the absence of clear boundaries between music and dance forms, in samba culture.

Dance studies The generality of our methods increases the potential impact of our studies in the field of dance research. The focus on empirical methods based on low-level features of movement and the focus on a conceptual background on cognition, perception, movement science and computational techniques, guarantees that our approaches can be fully extended to a myriad of music-dance forms. These approaches may become especially relevant to the study of popular or traditional dances which have been extensively studied in humanities but rarely investigated from the viewpoint of movement and sound. These dance cultures are found in global and local trends, new and old traditions, and influence a vibrant industry of entertainment. Most of these cultures share the same cross-modality of the samba traditions and exhibit choreographic displays with repetitive gestural vocabularies. Our approaches include the use of new technologies and provide important connections that can be used in the development of new technologies for performance, archiving, analysis and assessment of dance.

Knowledge about samba forms We have contributed to the panorama of cultural studies in Afro-Brazilian culture by providing systematic accounts of gesture in dance and music that were not envisaged before at this level of detail and range of observation. We especially increased our musicological knowledge with regards to the domains dance, whose connection have repeatedly been stressed in all the sources of tacit and explicit knowledge on samba culture. We have reinforced the argument about the role of rhythmic ambiguity in music and the role of enaction of meter in dance patterns. This argument provides elements to better understand the performance and evolution of samba forms, music and dance. It provides empirical, verifiable and conceptual backgrounds that help to understand the importance of embodiment in the Afro-Brazilian culture, which has always challenged researchers in the field.

8.3.1 Future studies

Research in gesture needs to combine recent developments on gestural interfaces with a more comprehensive heuristics that takes into account semantics distributed in other domains, cultural maps and niches, its limitations and its levels of indeterminacy and variability. The development of new forms of description of variability must be seriously taken into account in order to cope with the specificities of the research universes in music, dance and art.

Future applications of our approaches could be further developed and implemented in the field of dance analysis, dance performance and preservation of intangible heritage such as popular dances and music. The representations of gesture here proposed could offer a methodological and conceptual basis for the development of mappings between media and movement, assessment of qualities of movement and analysis of dance characteristics, tendencies and structures in contemporary or popular dances. Applications could be also used in methods for registering and reporting disappearing dance traditions and for the development of archiving enriched digital objects.

More research is needed in order to deal with the topological information of the dance gesture. With the TGA approach, we made a first attempt to map the topology of the dance space with musical qualities. Further studies should also take into account other musical characteristics and different contexts of musical/choreographic relationships. The features provided by the topological maps must be streamlined and further developed in combination with approaches such as qualitative reasoning calculus or other appropriate forms of logic.

Finally, more research is needed on music and music information retrieval in order to unravel the mechanisms that characterize basic motivic forms found not only in samba music, but in the panorama of the African diaspora in the Americas. More data-sets are needed in order to provide better statistical accounts of the tendencies of rhythm, timbre, harmony, melody and microtiming that populate the matrix Latin-American music traditions. More interestingly, these accounts should be accompanied by better descriptions of dances that systematically occur with music traditions in Brazil, Latin-America, Africa and other cultures.

A
Topological Gesture Analysis of Samba Dance

The results displayed in the next pages are described in Section 7.3

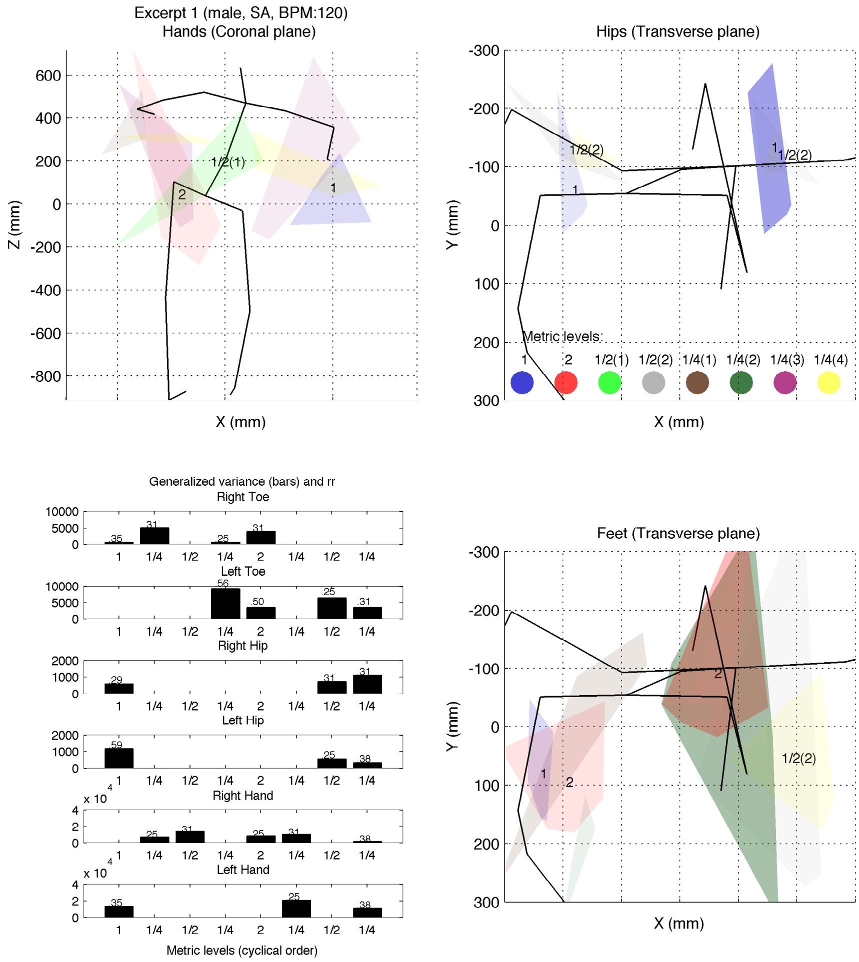


Figure A.1: Representation of the topological abstractions for the excerpt 1 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

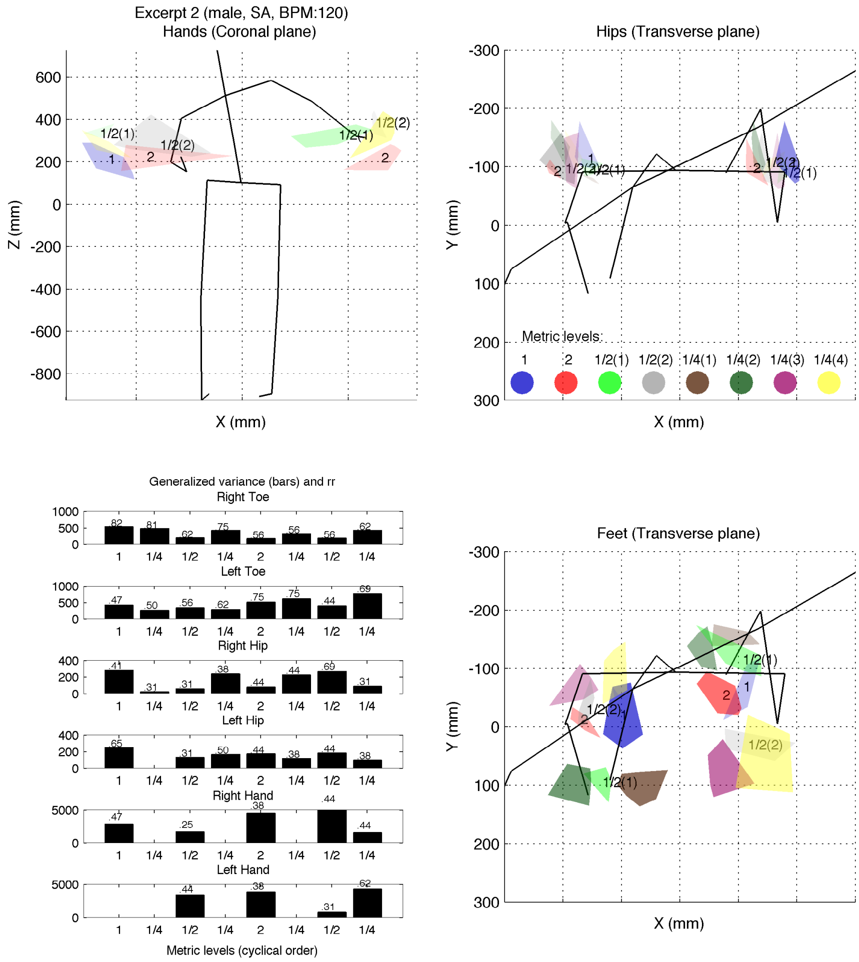


Figure A.2: Representation of the topological abstractions for the excerpt 2 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

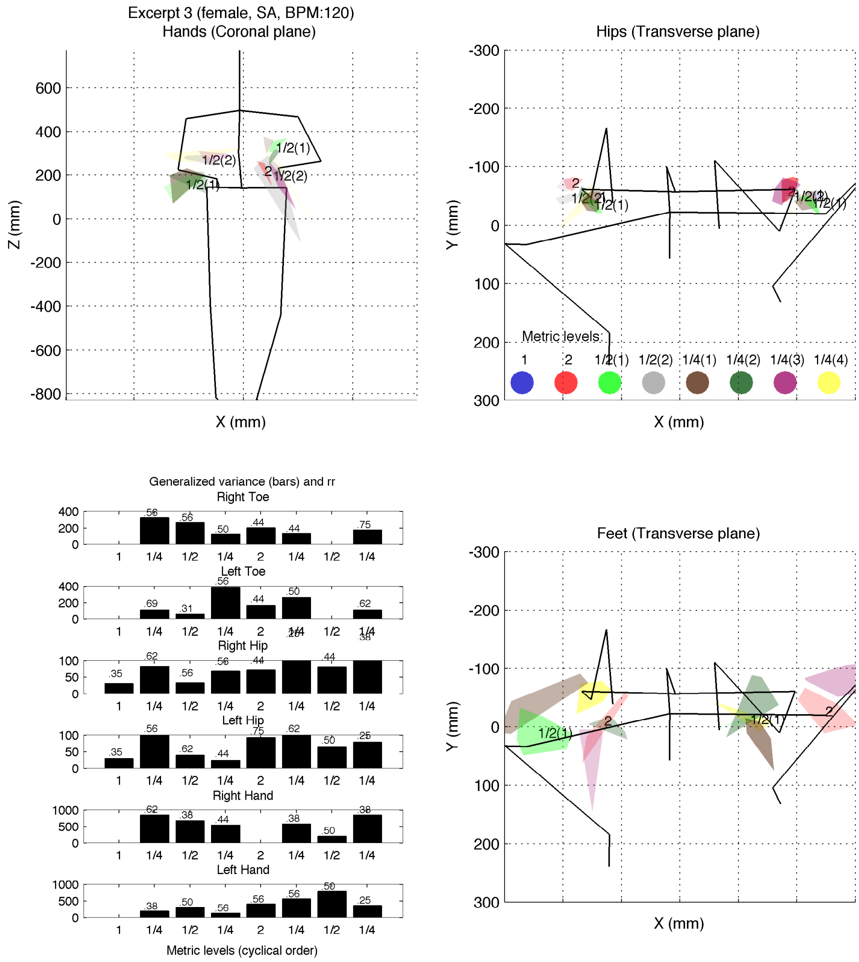


Figure A.3: Representation of the topological abstractions for the excerpt 3 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

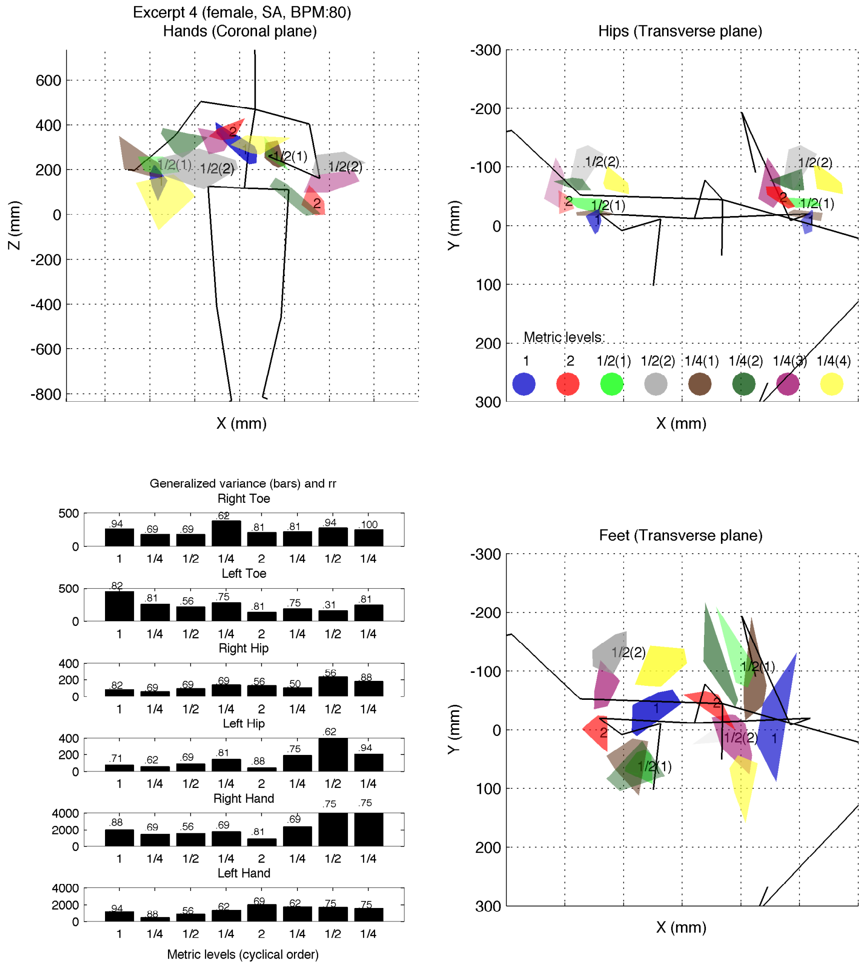


Figure A.4: Representation of the topological abstractions for the excerpt 4 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

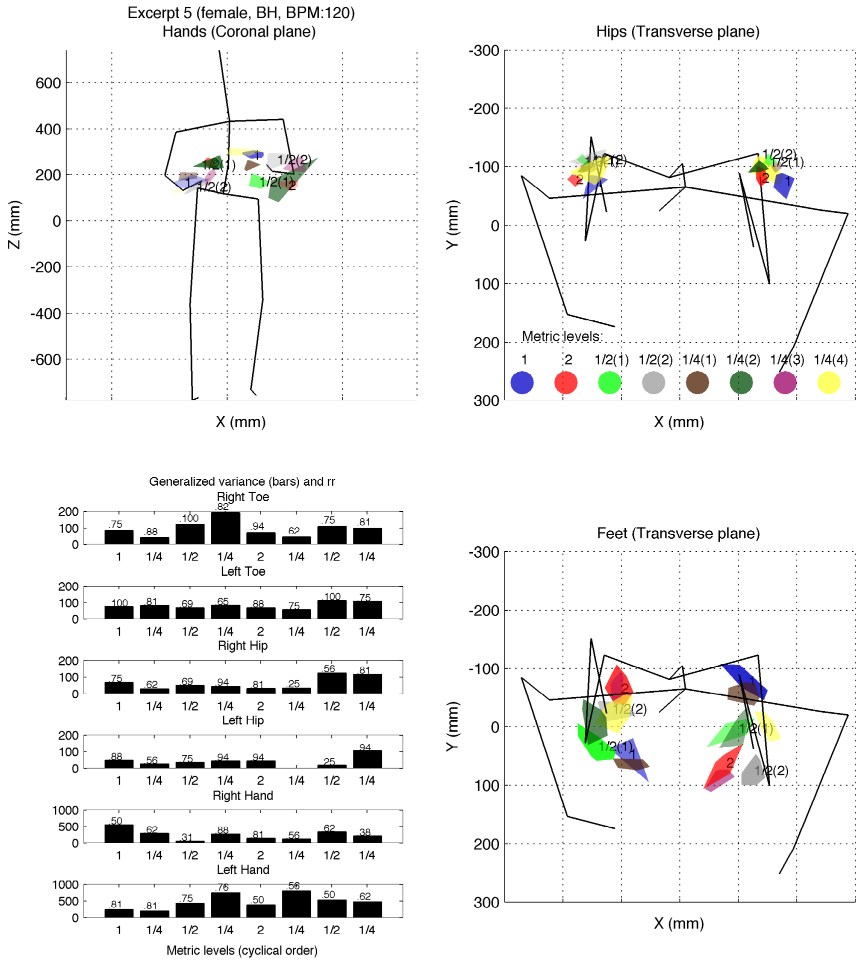


Figure A.5: Representation of the topological abstractions for the excerpt 5 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

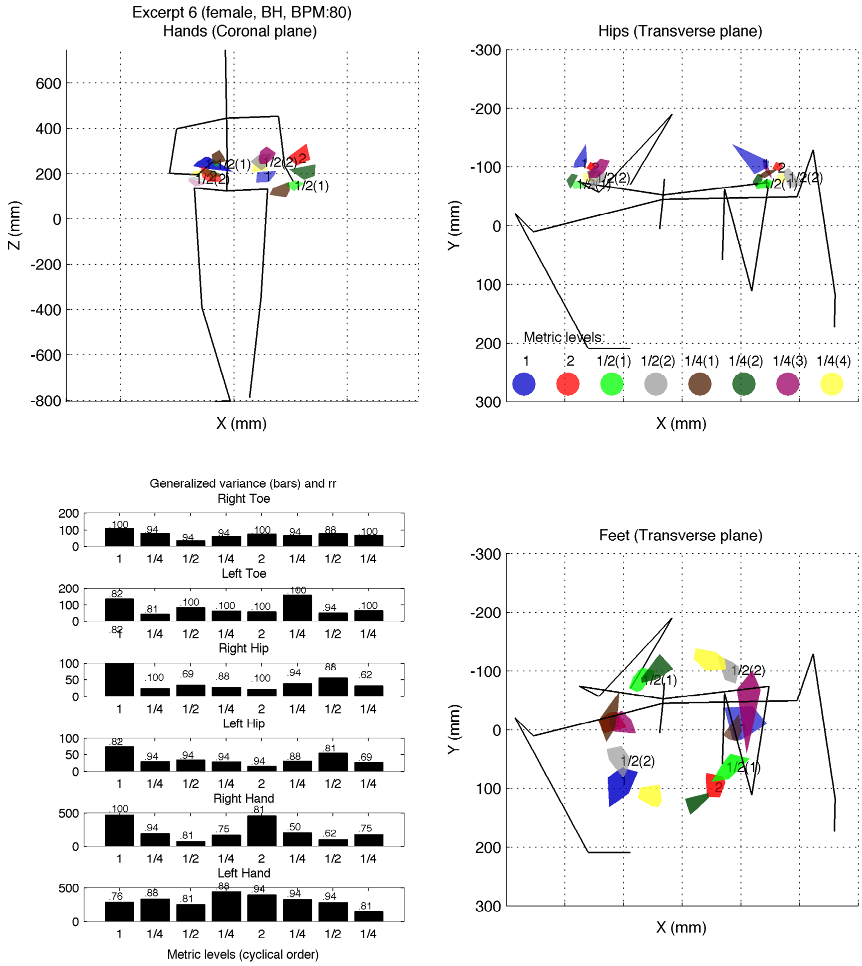


Figure A.6: Representation of the topological abstractions for the excerpt 6 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

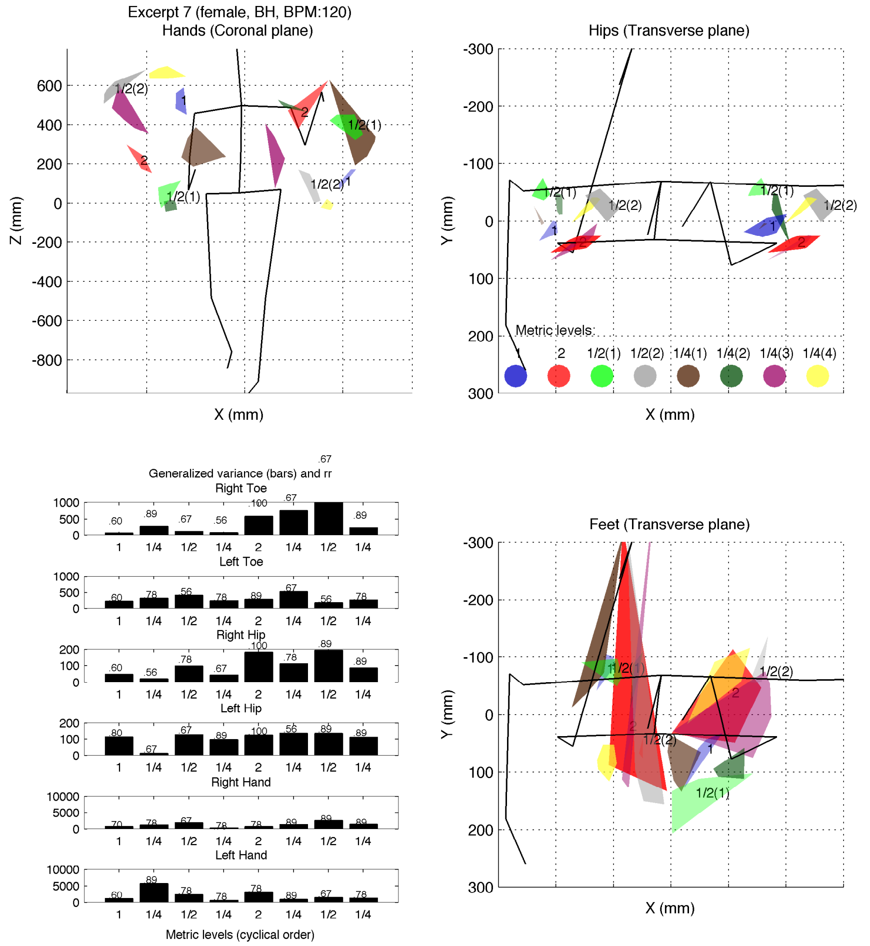


Figure A.7: Representation of the topological abstractions for the excerpt 7 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

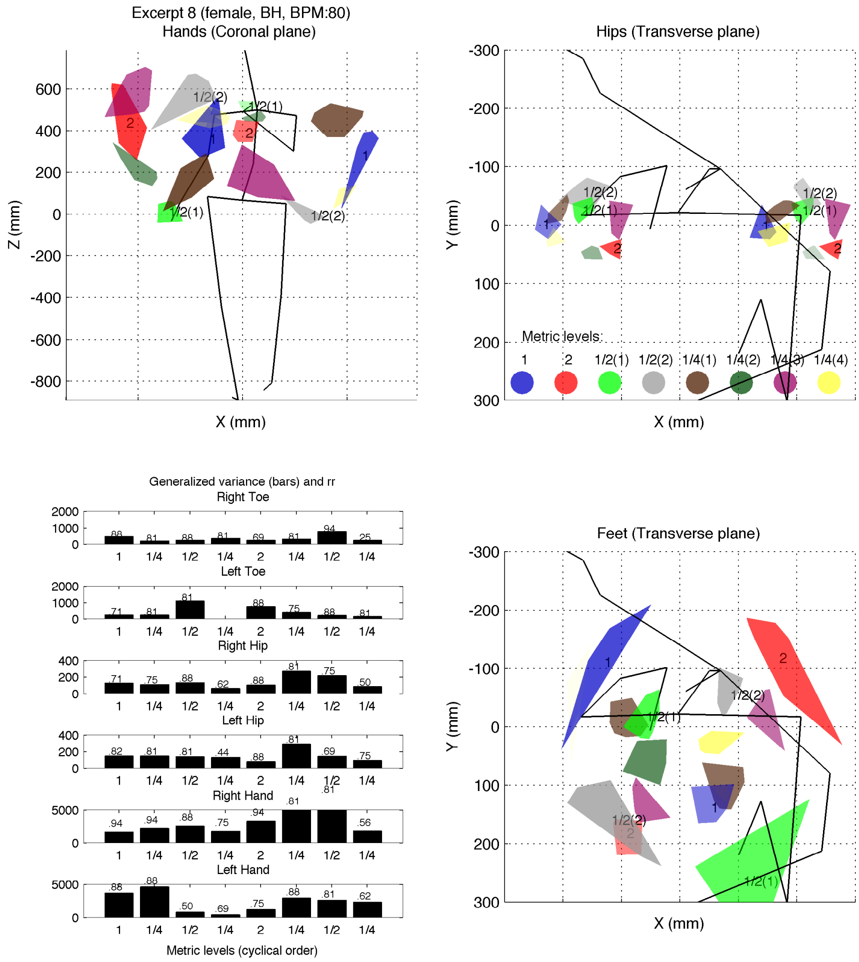


Figure A.8: Representation of the topological abstractions for the excerpt 8 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

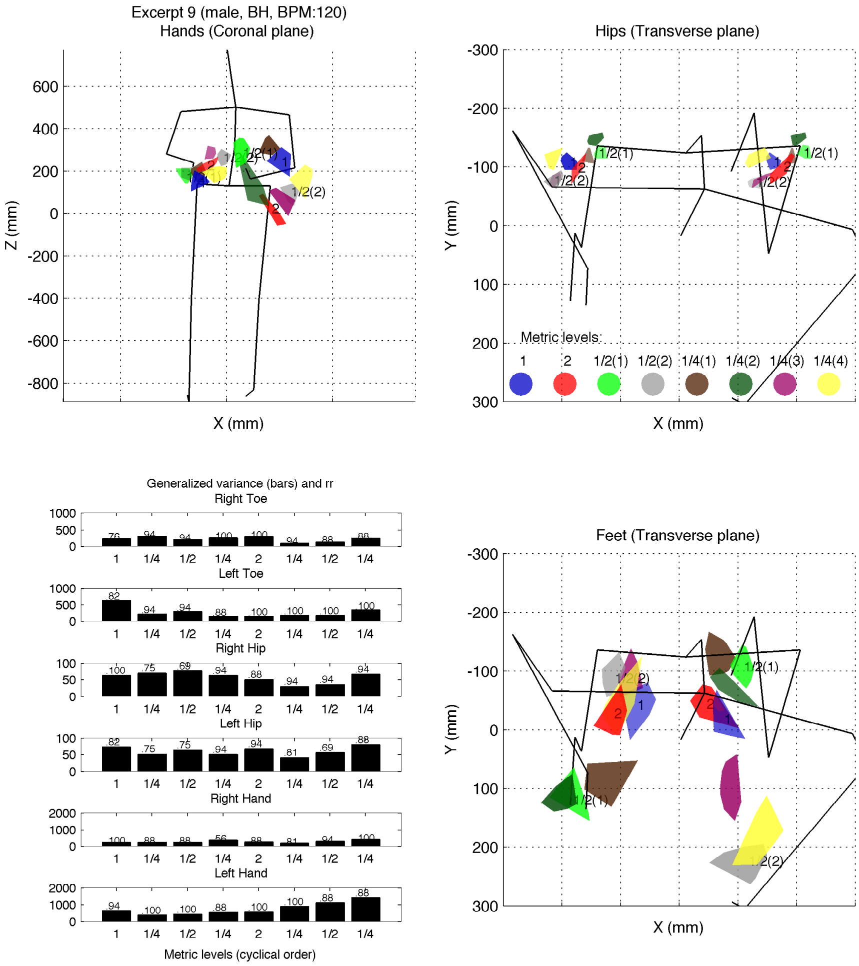


Figure A.9: Representation of the topological abstractions for the excerpt 9 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

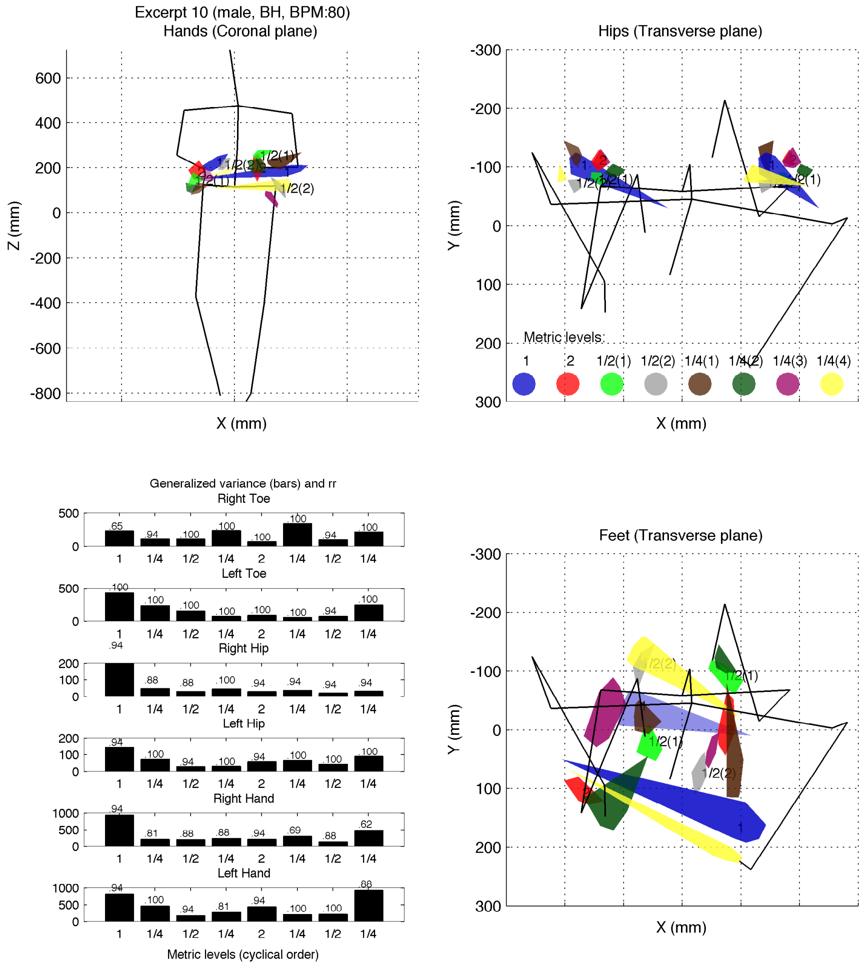


Figure A.10: Representation of the topological abstractions for the excerpt 10 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

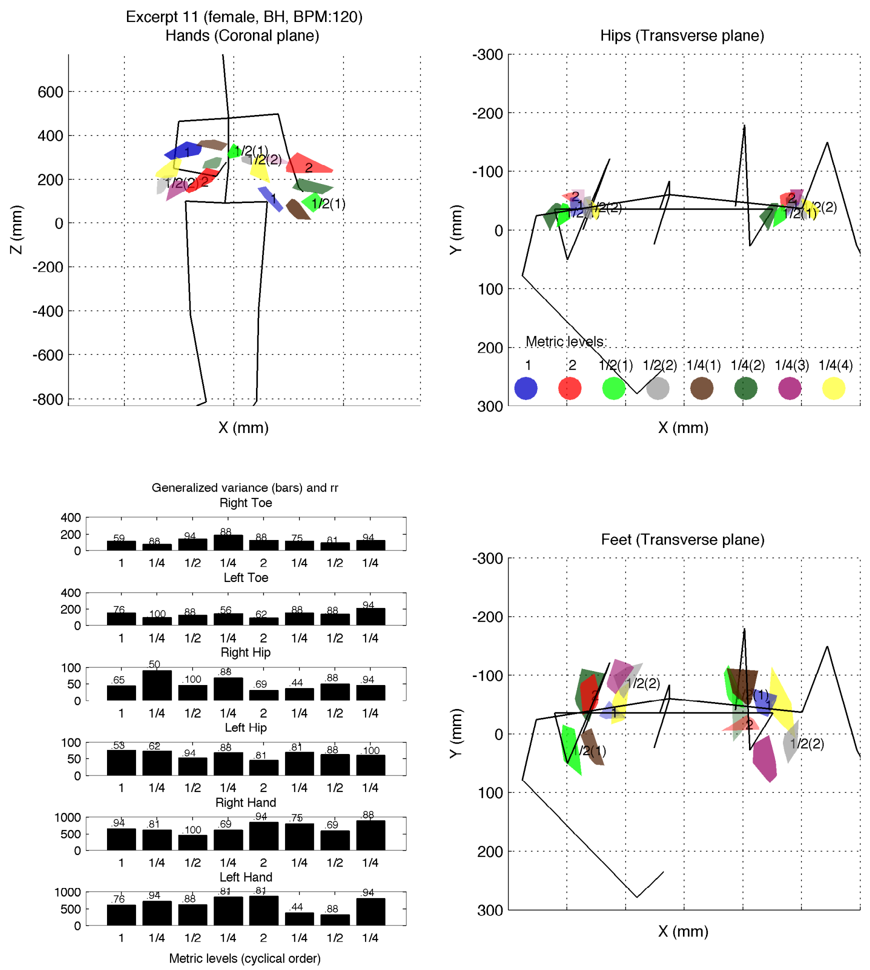


Figure A.11: Representation of the topological abstractions for the excerpt 11 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

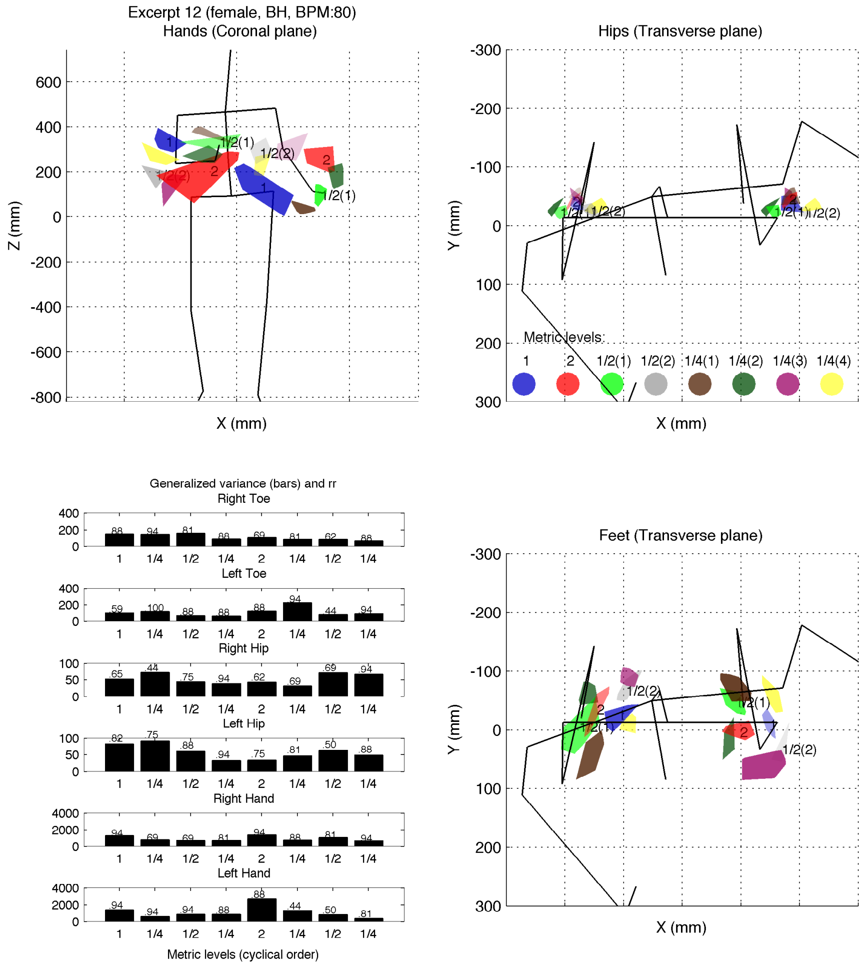


Figure A.12: Representation of the topological abstractions for the excerpt 12 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

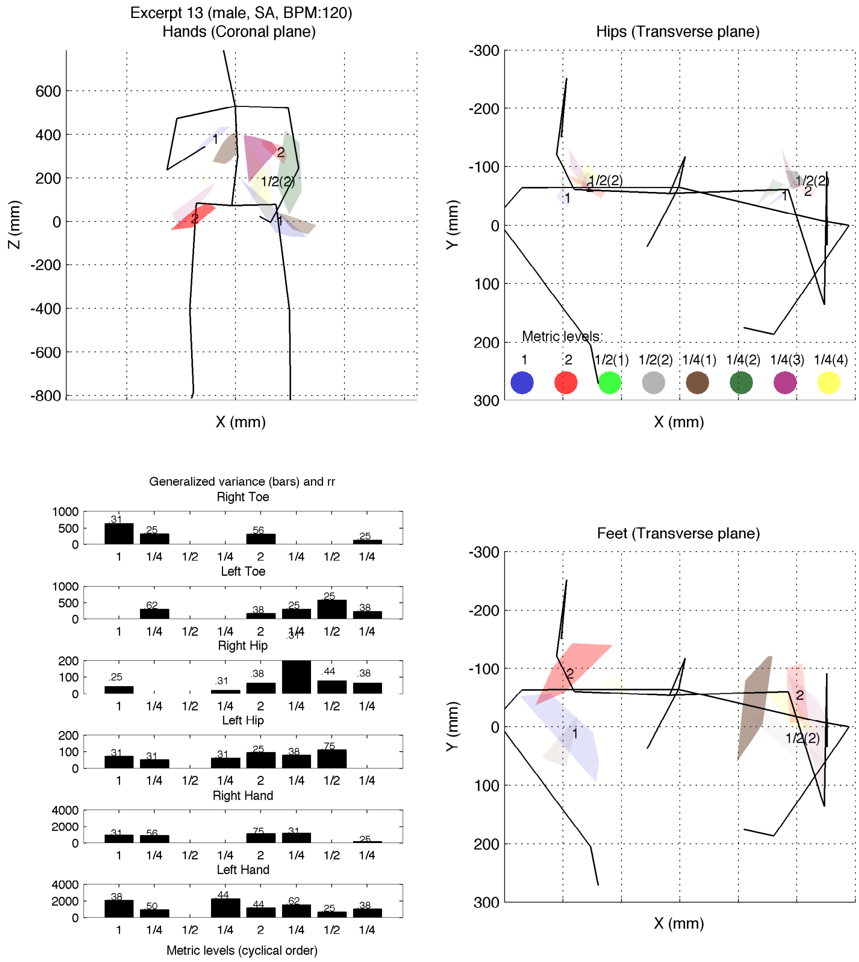


Figure A.13: Representation of the topological abstractions for the excerpt 13 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

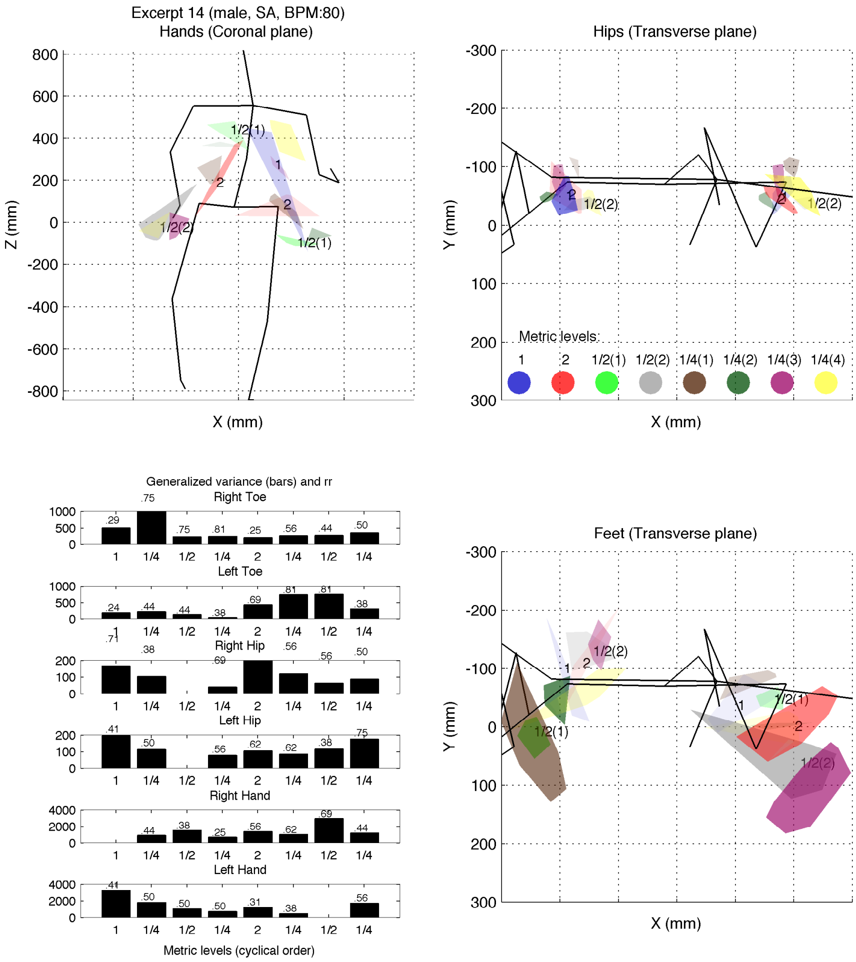


Figure A.14: Representation of the topological abstractions for the excerpt 14 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

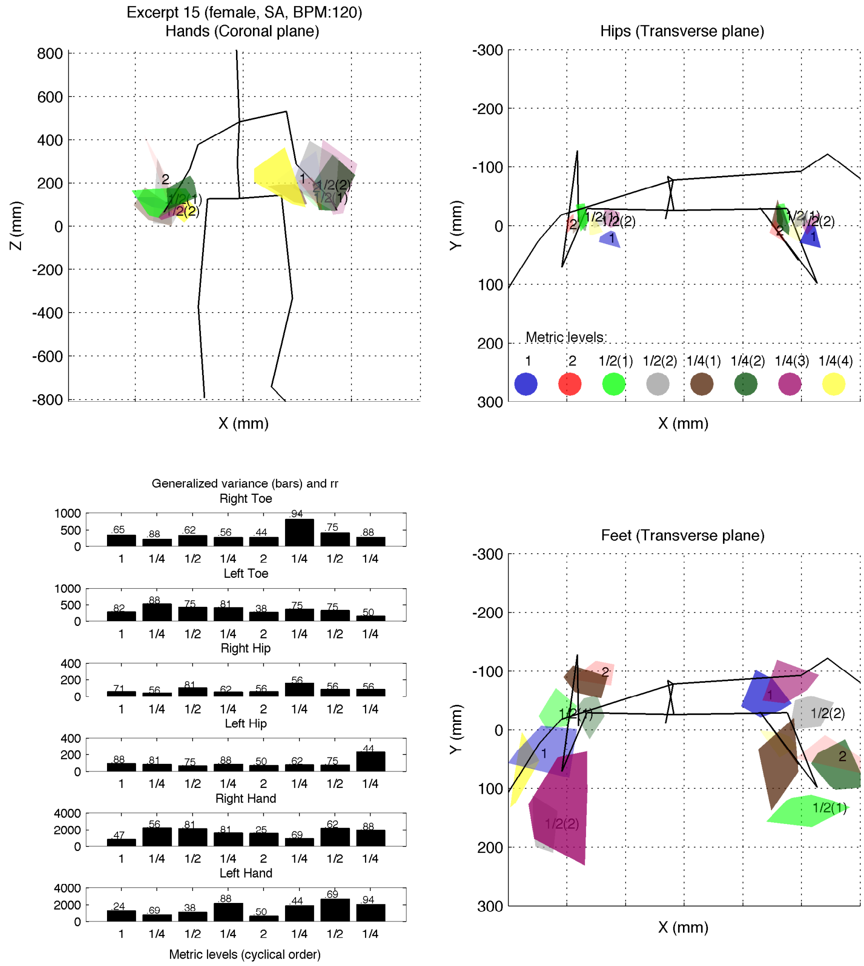


Figure A.15: Representation of the topological abstractions for the excerpt 15 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

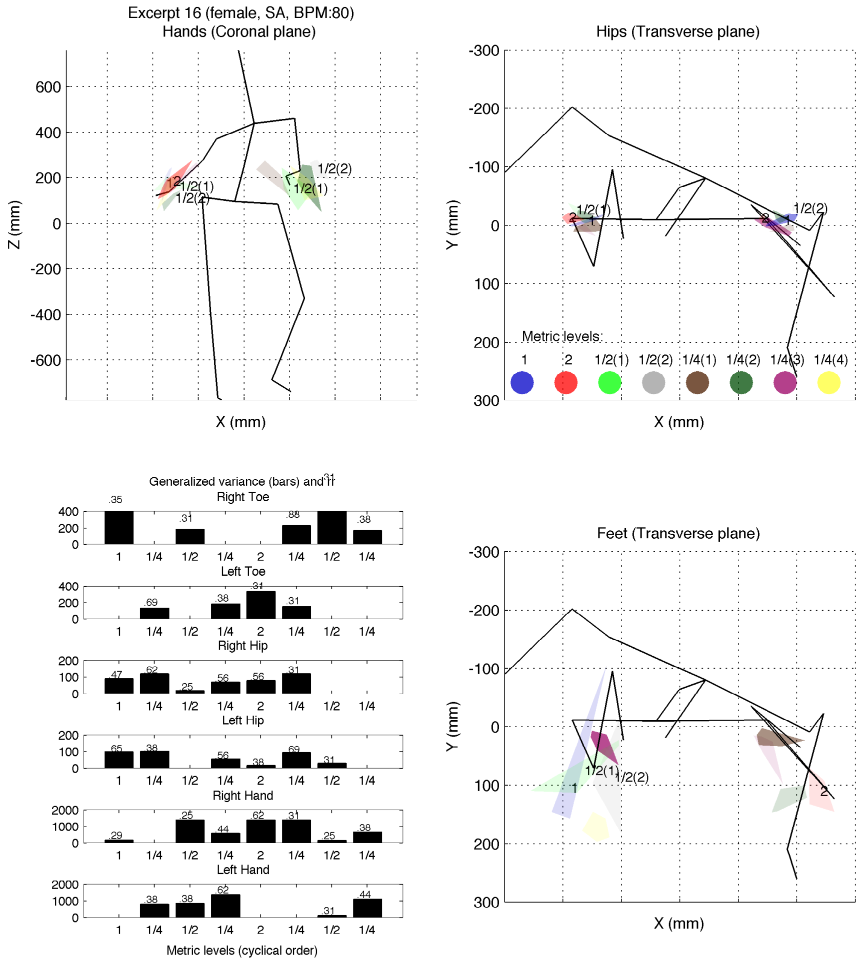


Figure A.16: Representation of the topological abstractions for the excerpt 16 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

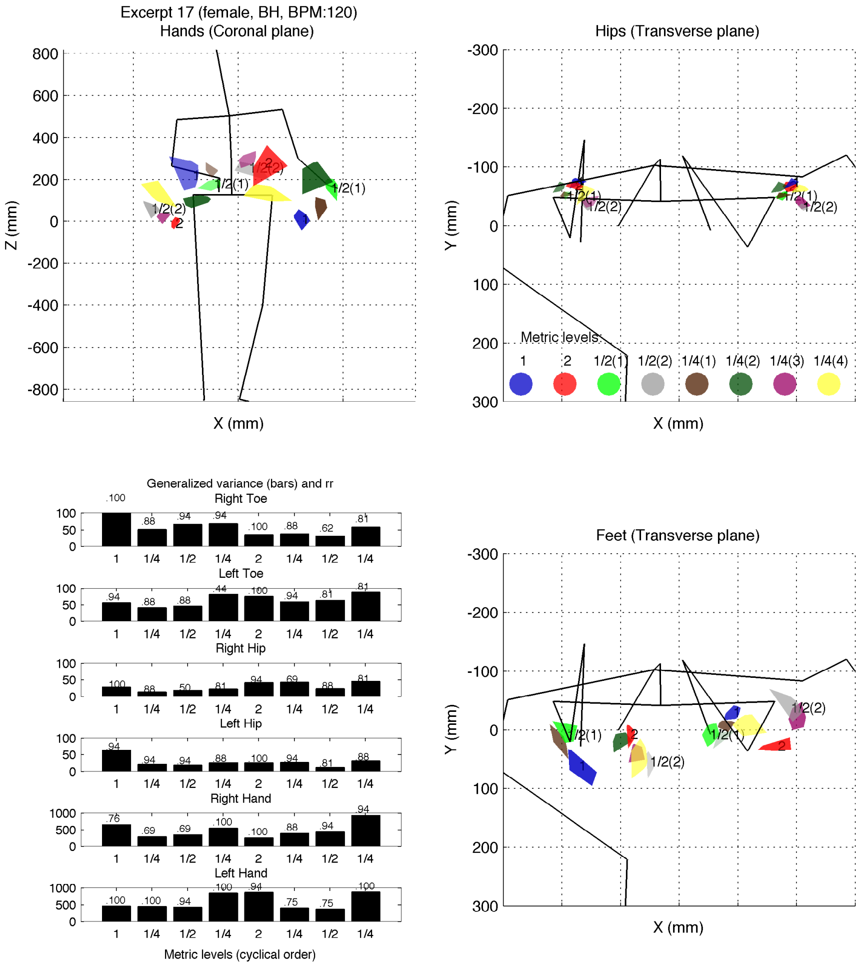


Figure A.17: Representation of the topological abstractions for the excerpt 17 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

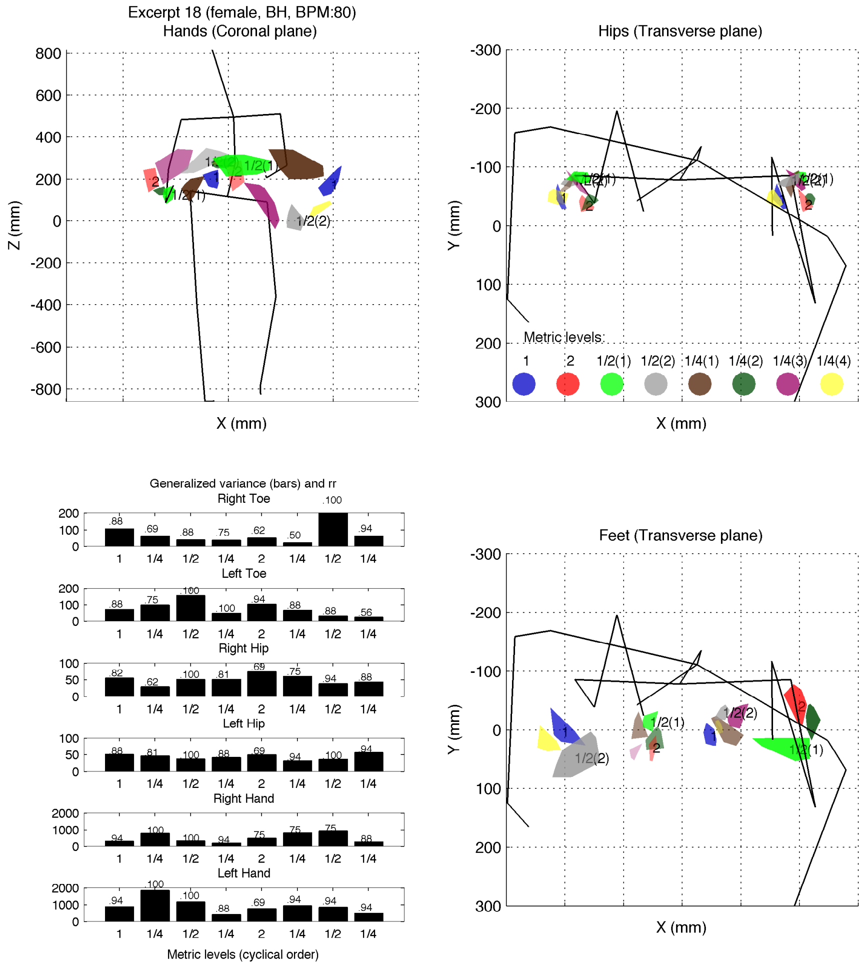


Figure A.18: Representation of the topological abstractions for the excerpt 18 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

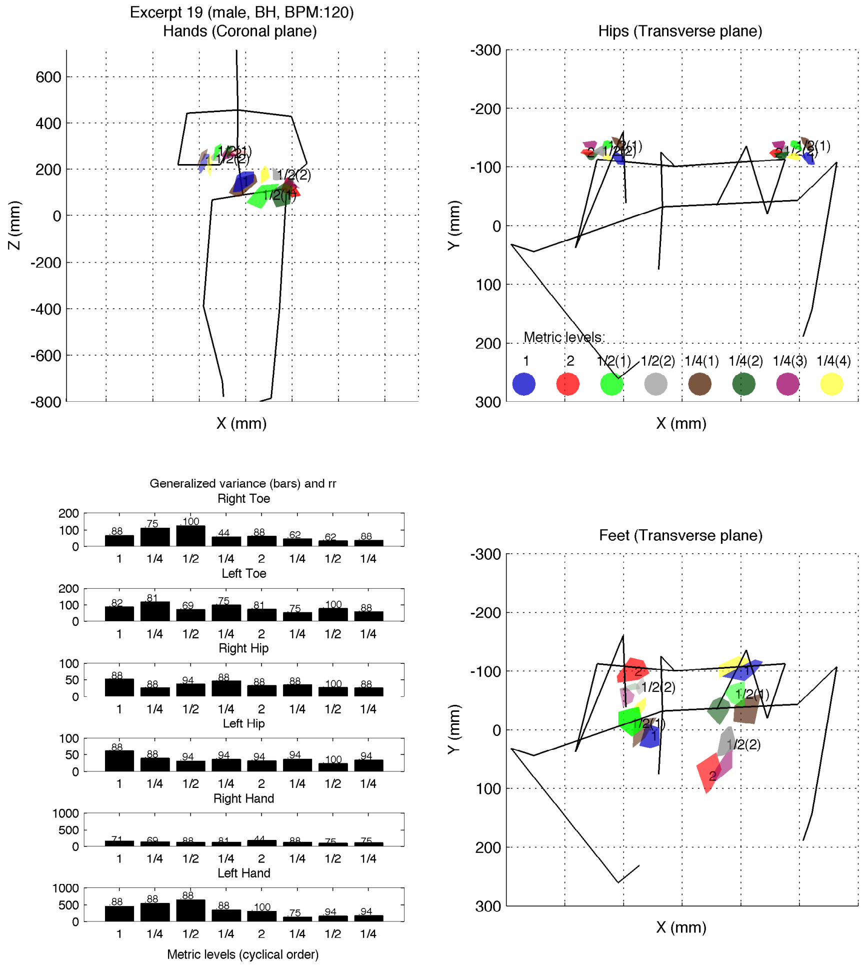


Figure A.19: Representation of the topological abstractions for the excerpt 19 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

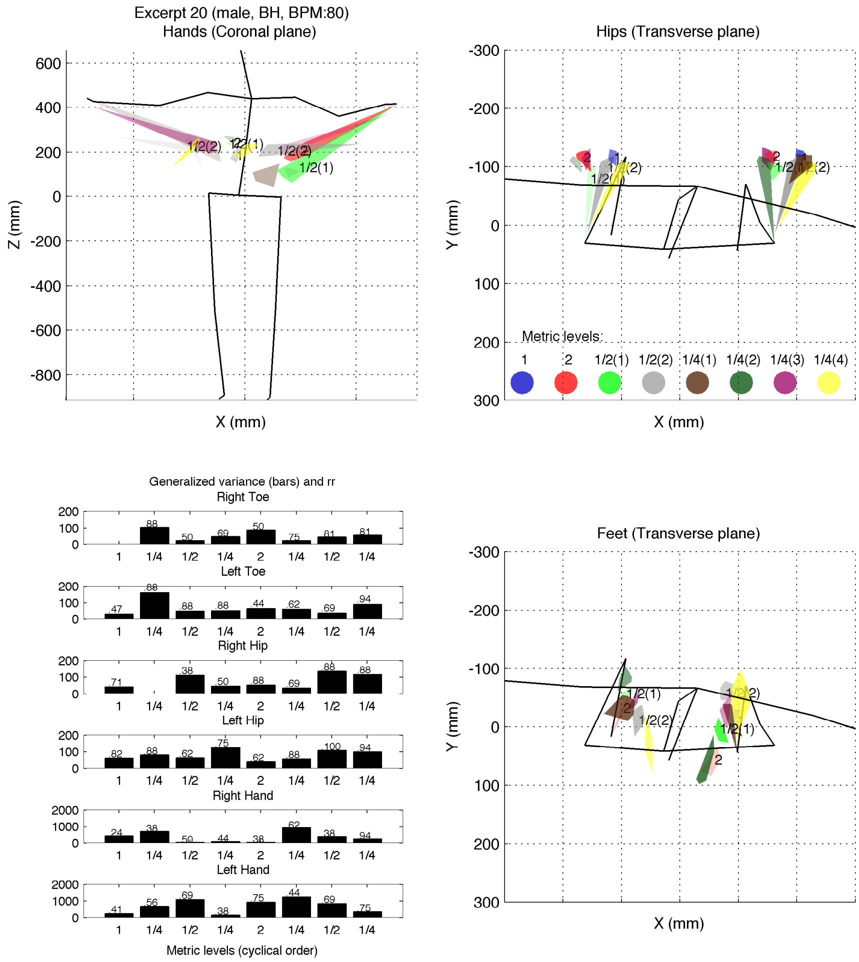


Figure A.20: Representation of the topological abstractions for the excerpt 20 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

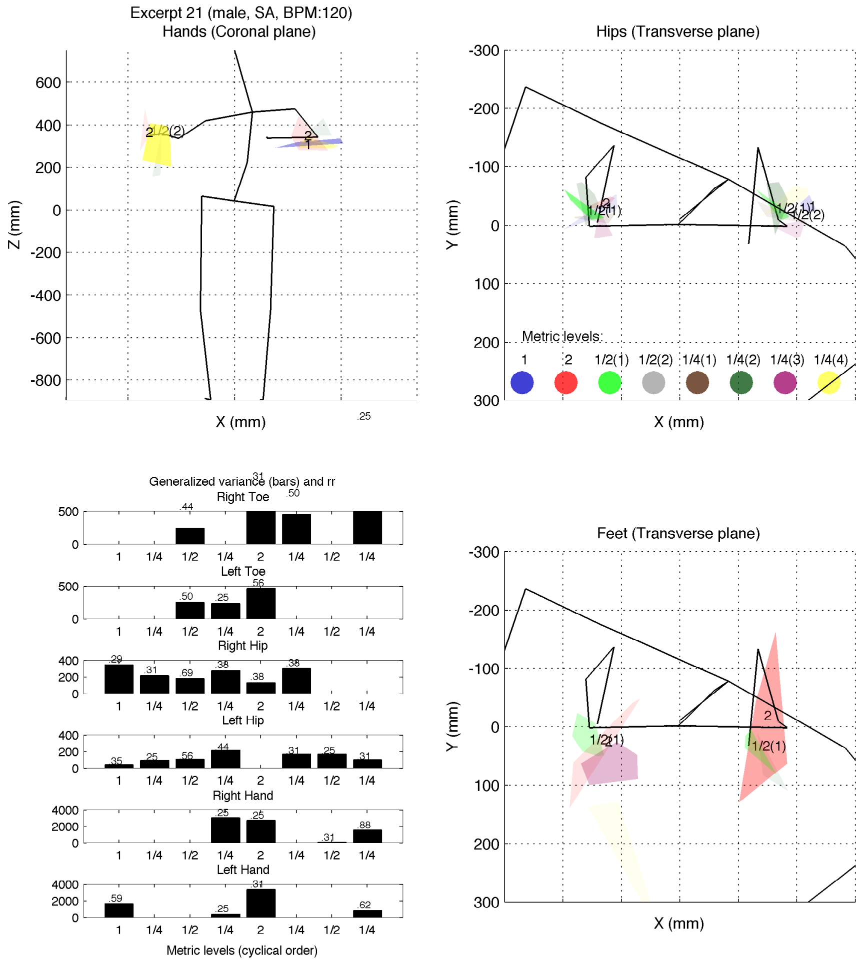


Figure A.21: Representation of the topological abstractions for the excerpt 21 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

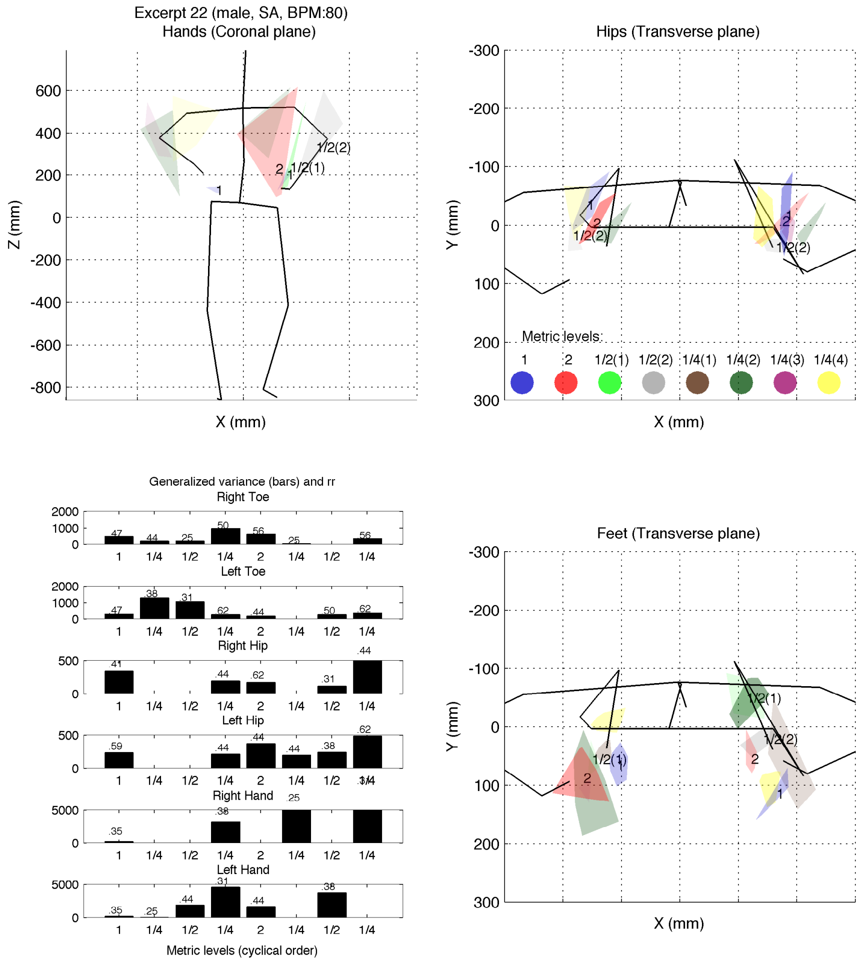


Figure A.22: Representation of the topological abstractions for the excerpt 22 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

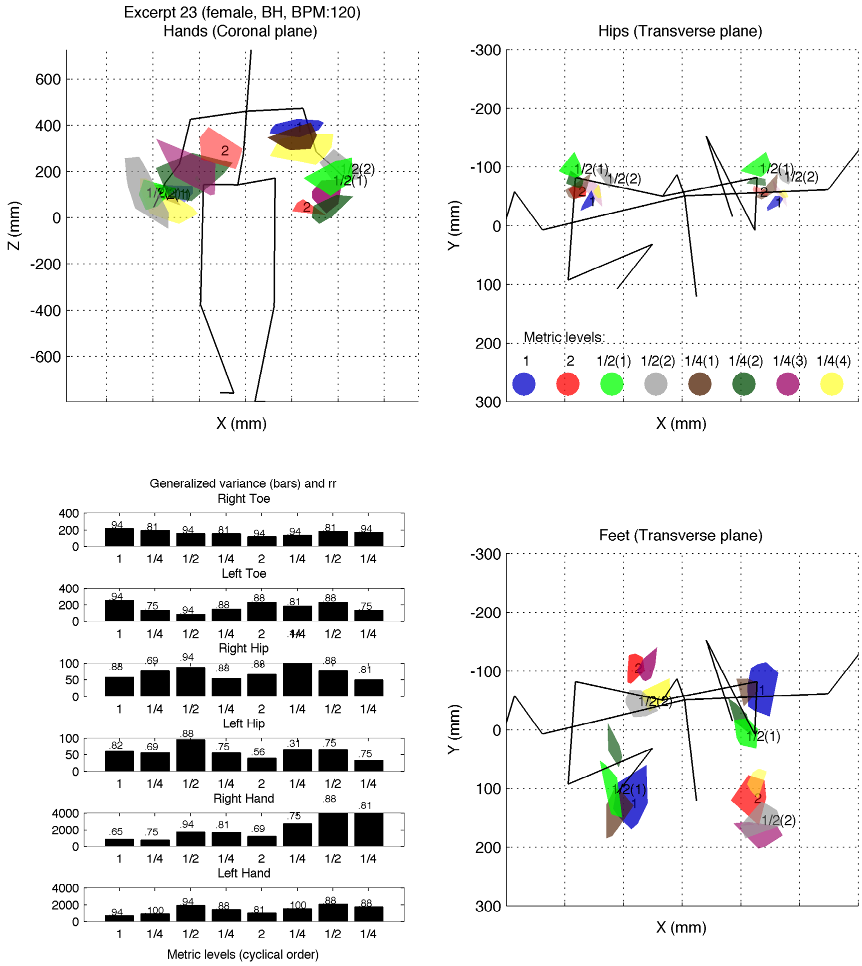


Figure A.23: Representation of the topological abstractions for the excerpt 23 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

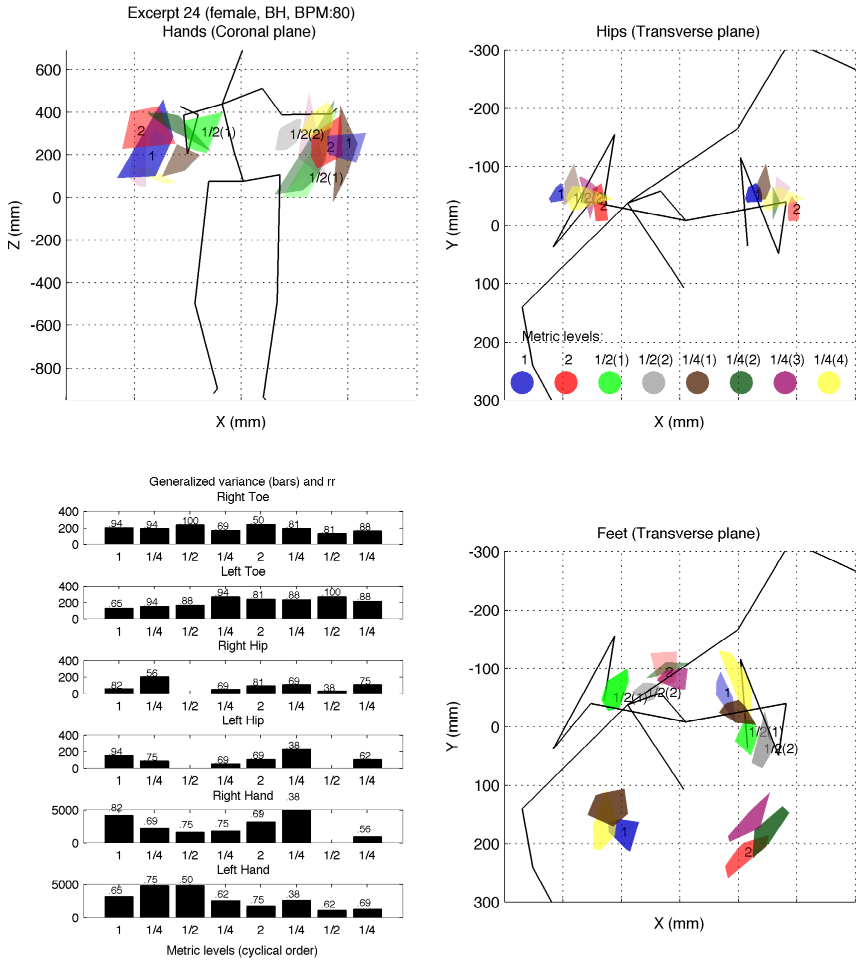


Figure A.24: Representation of the topological abstractions for the excerpt 24 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

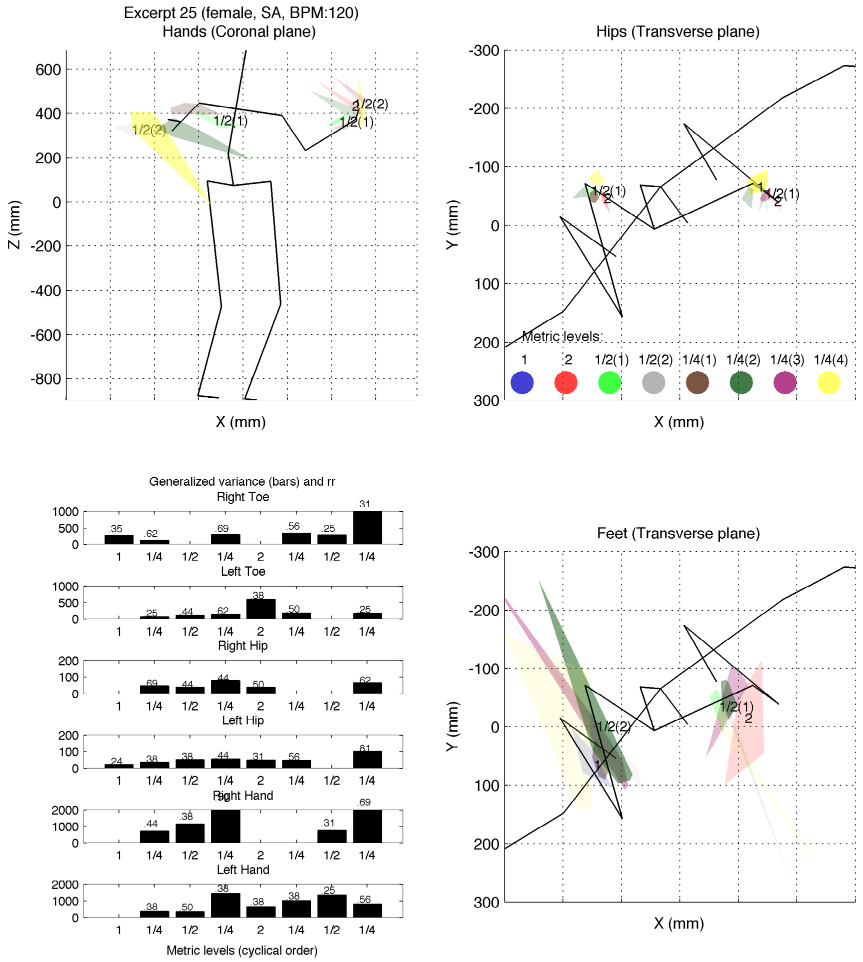


Figure A.25: Representation of the topological abstractions for the excerpt 25 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

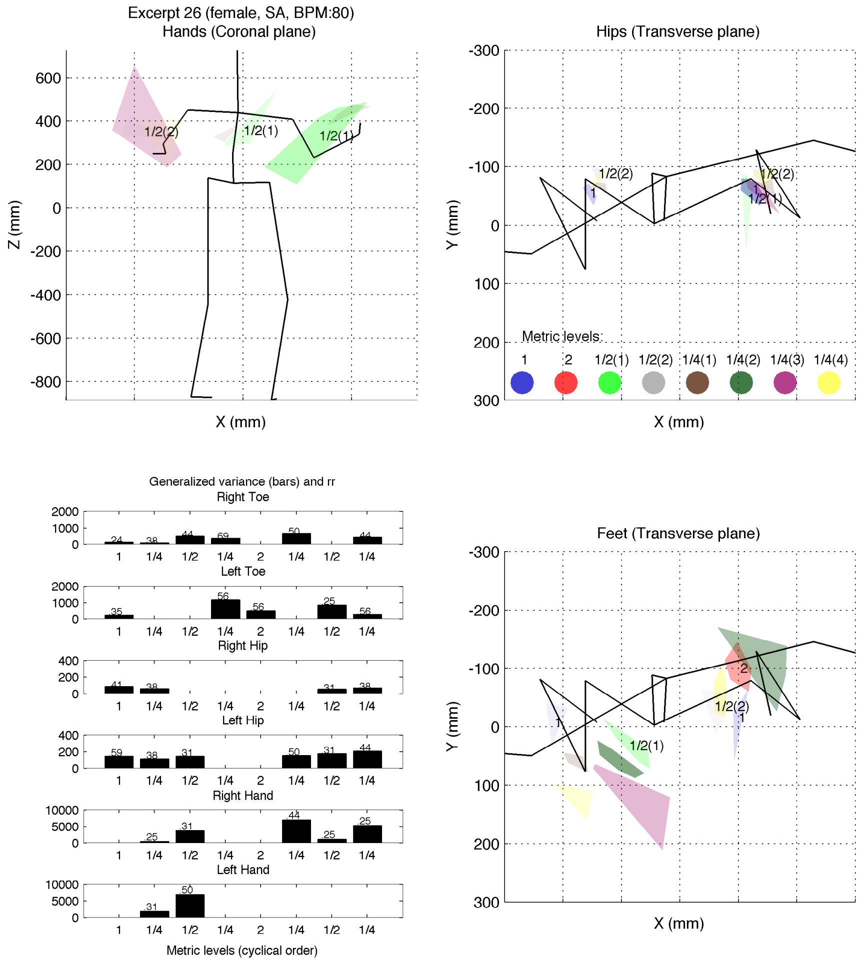


Figure A.26: Representation of the topological abstractions for the excerpt 26 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

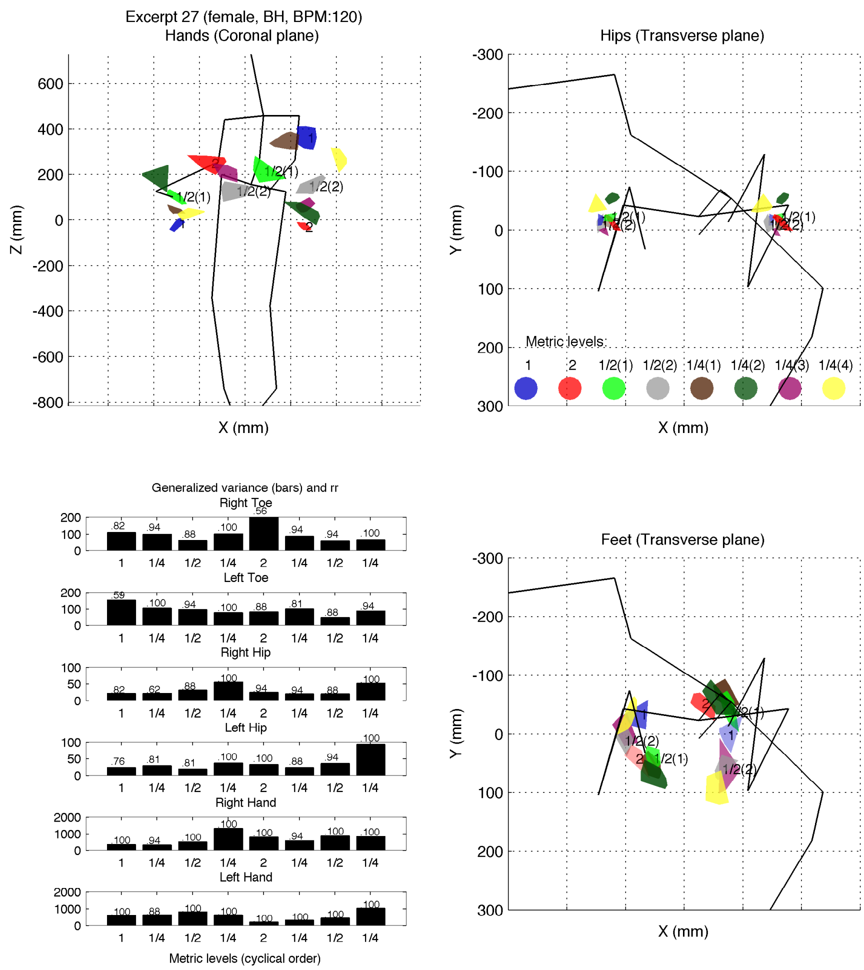


Figure A.27: Representation of the topological abstractions for the excerpt 27 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

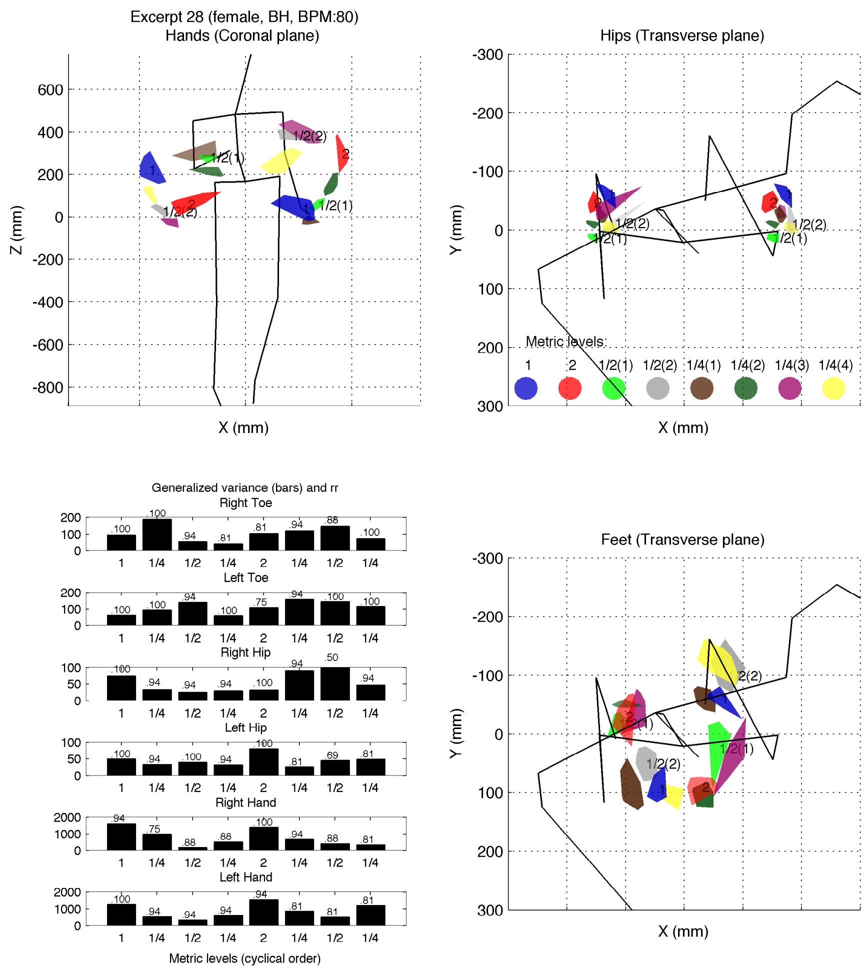


Figure A.28: Representation of the topological abstractions for the excerpt 28 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

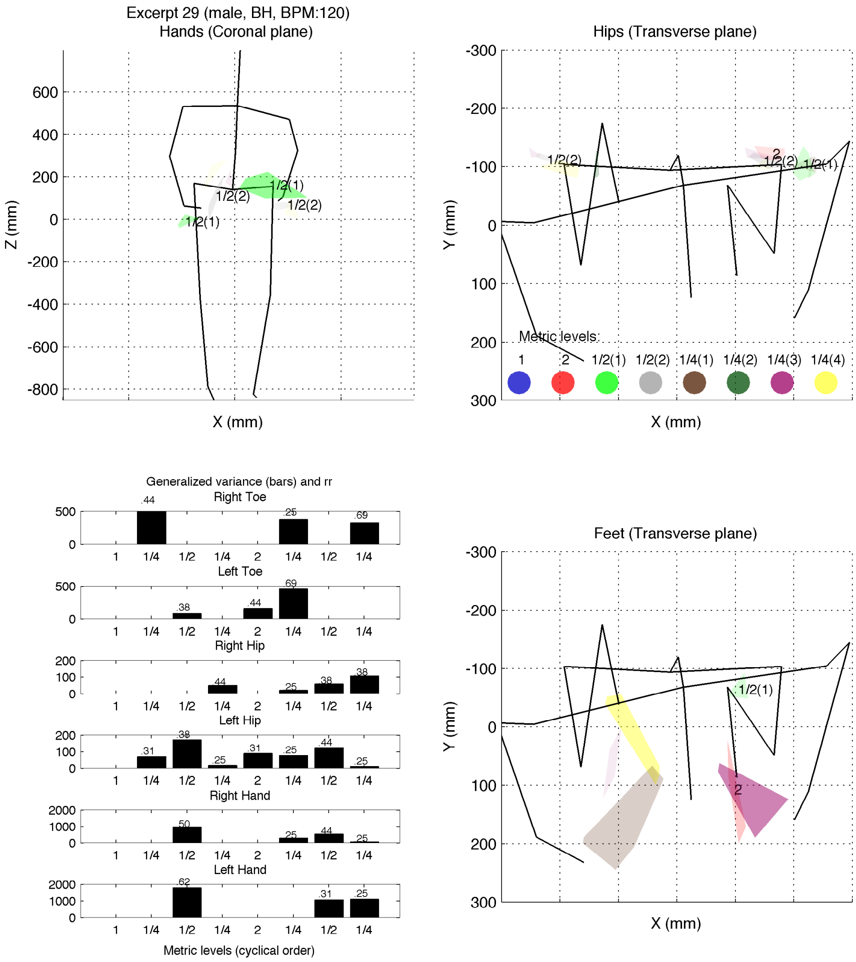


Figure A.29: Representation of the topological abstractions for the excerpt 29 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

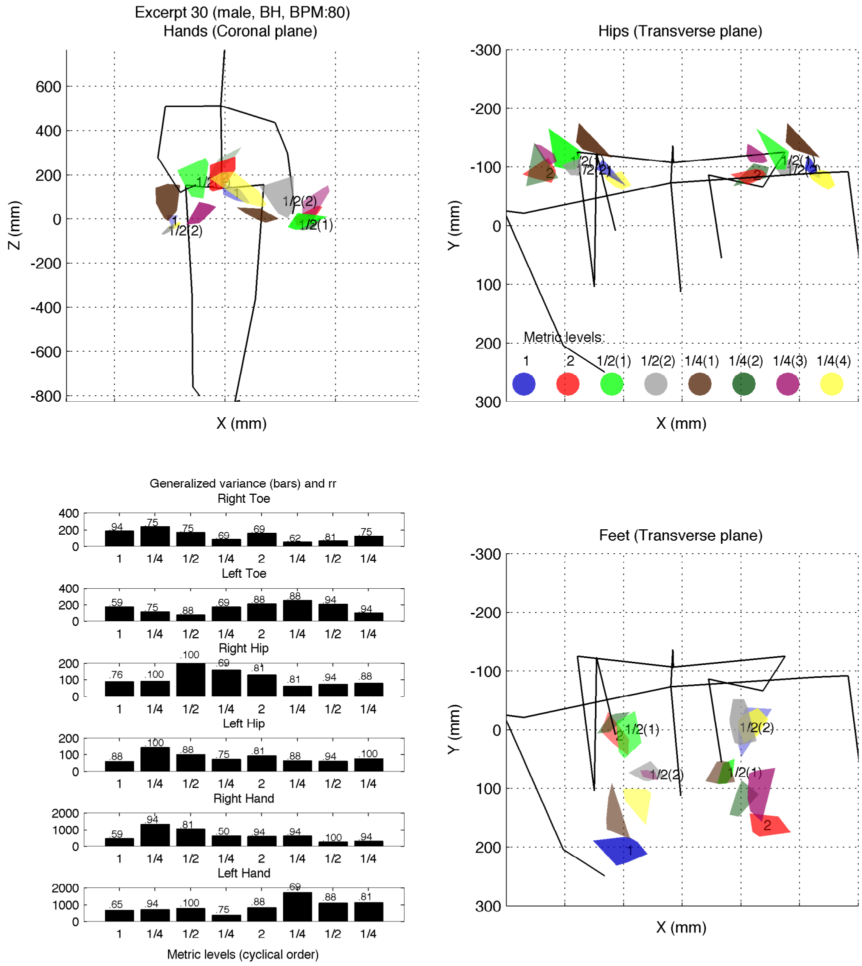


Figure A.30: Representation of the topological abstractions for the excerpt 30 (hands, hips and feet on the top and bottom-right graphs), generalized variance (bars) and ratio of recognition (ratio above bars). The numbers plotted against the topological representations indicate the metric levels. The level of transparency of the topological representations is (inversely) proportional to the ratio of recognition.

B

Basic Gestures of Samba Dance

The results displayed in the next pages are described in Section 7.4

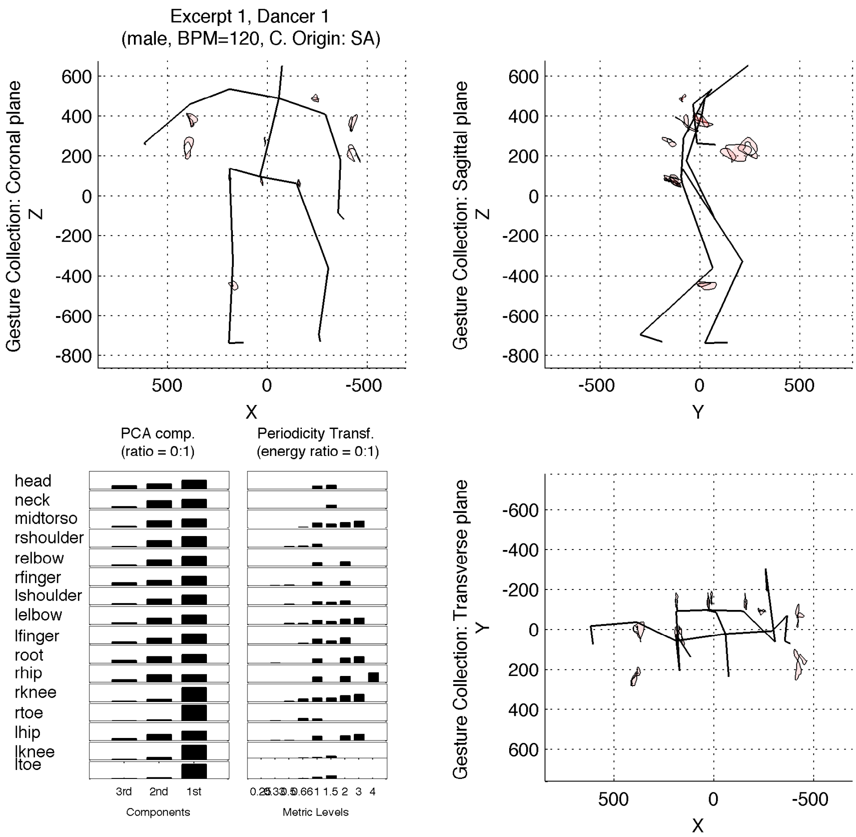


Figure B.1: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 1.

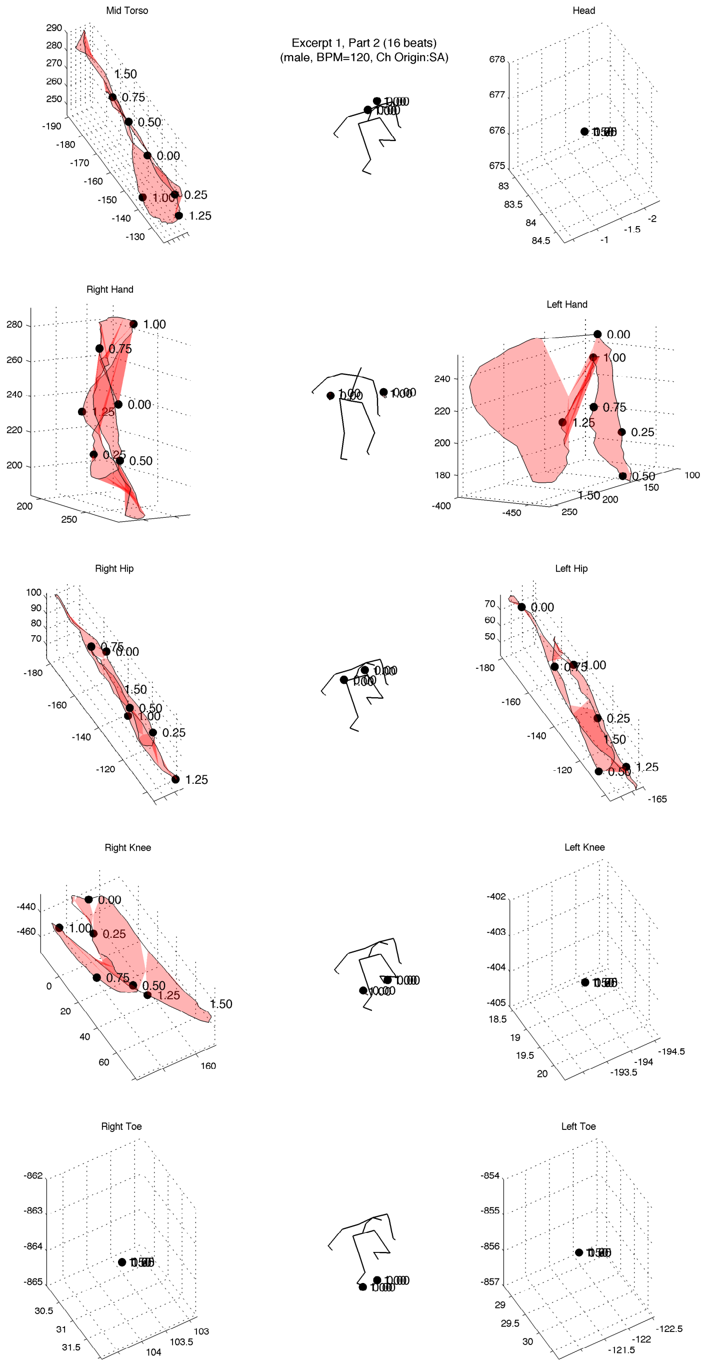


Figure B.2: Detailed view of the basic gestures for excerpt 1, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

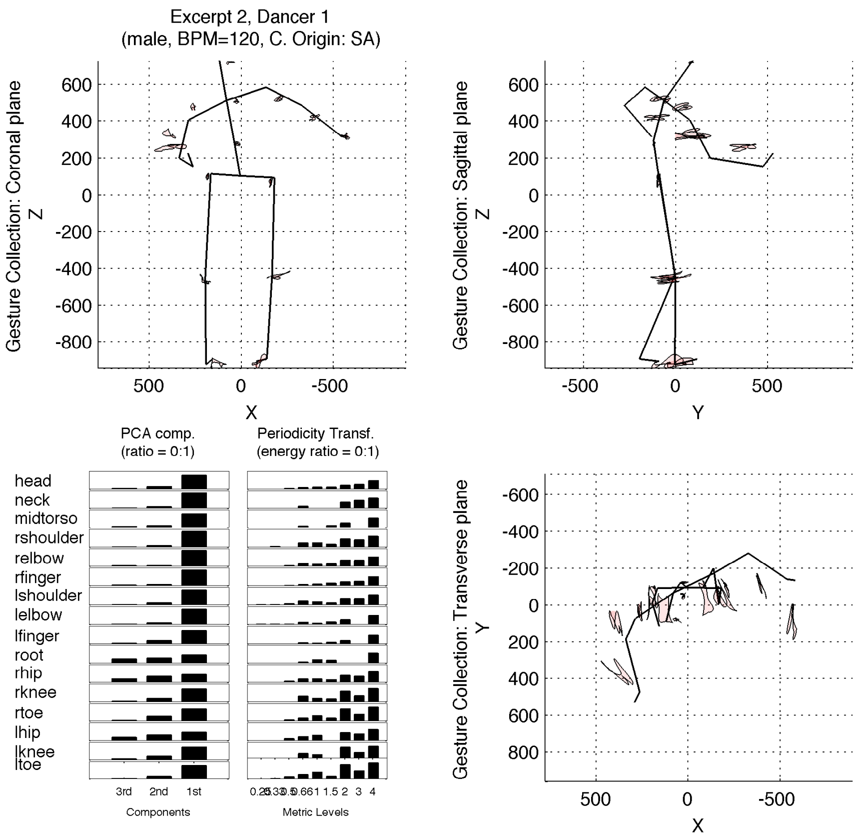


Figure B.3: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 2.

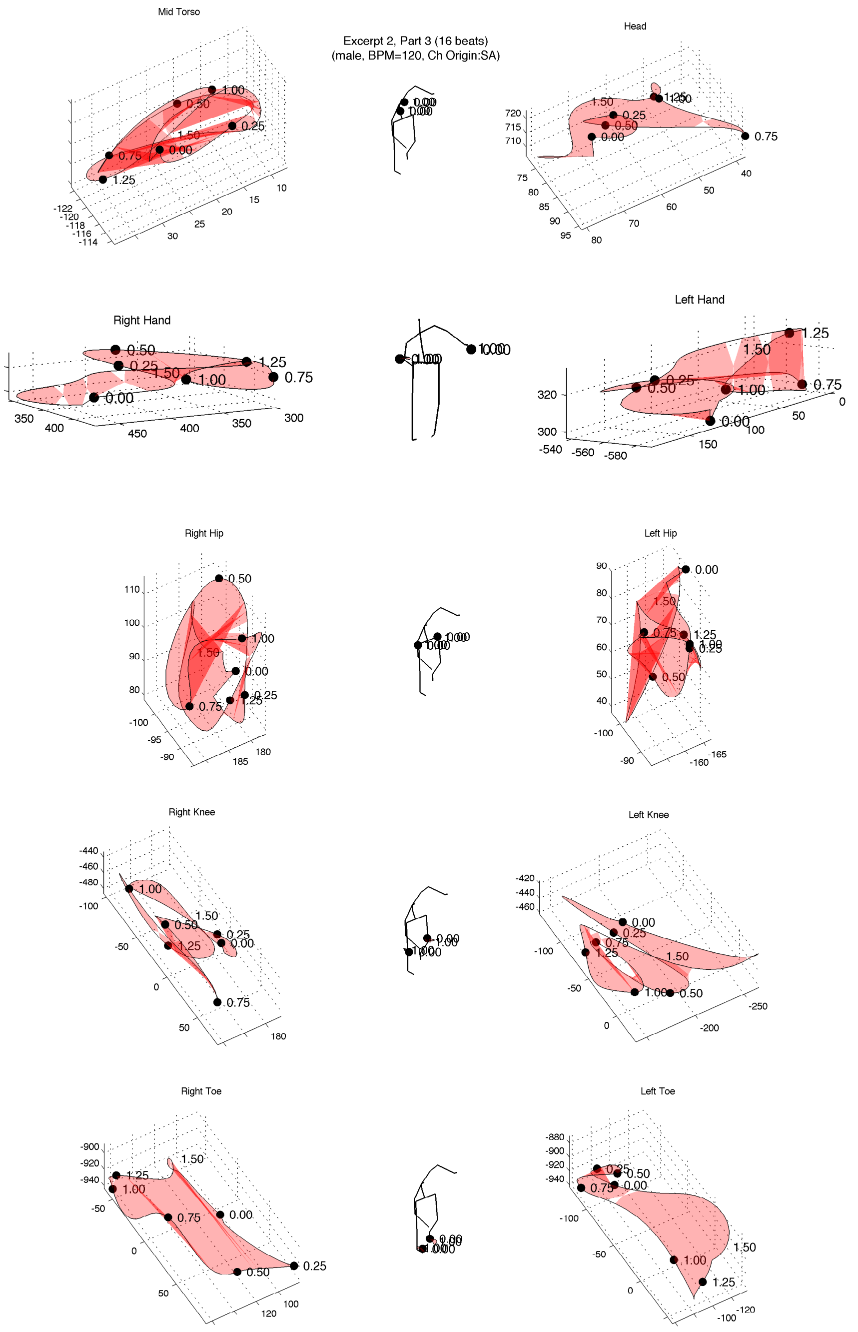


Figure B.4: Detailed view of the basic gestures for excerpt 2, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

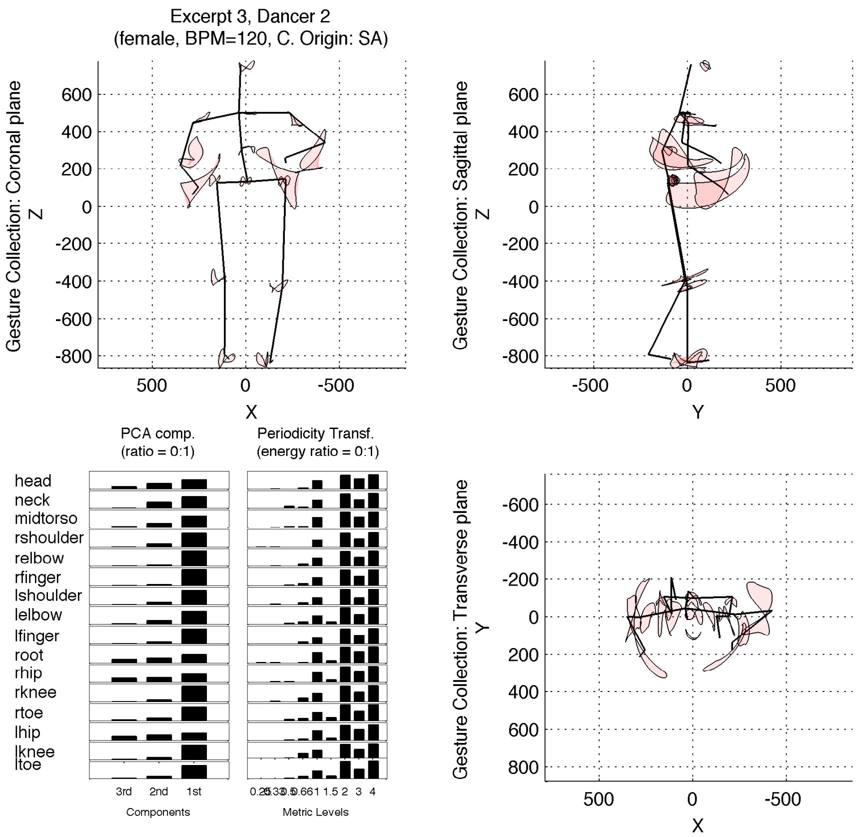


Figure B.5: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 3.

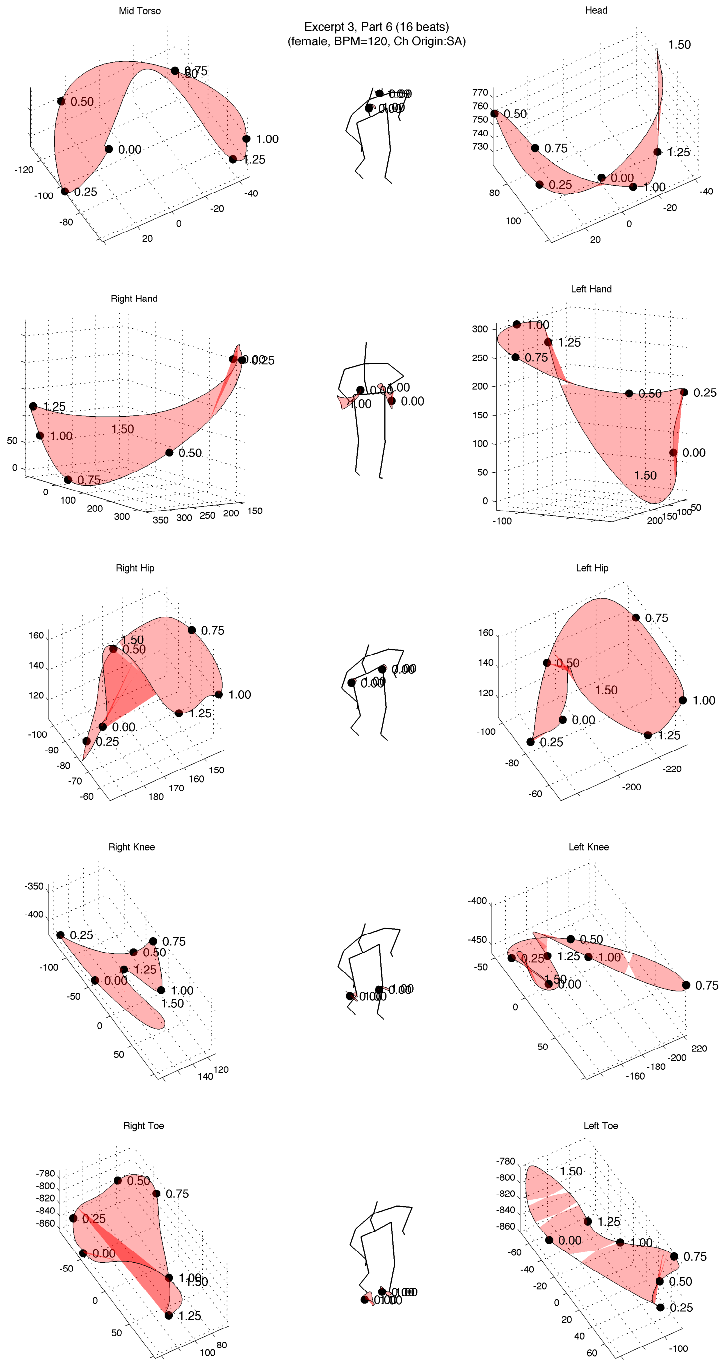


Figure B.6: Detailed view of the basic gestures for excerpt 3, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

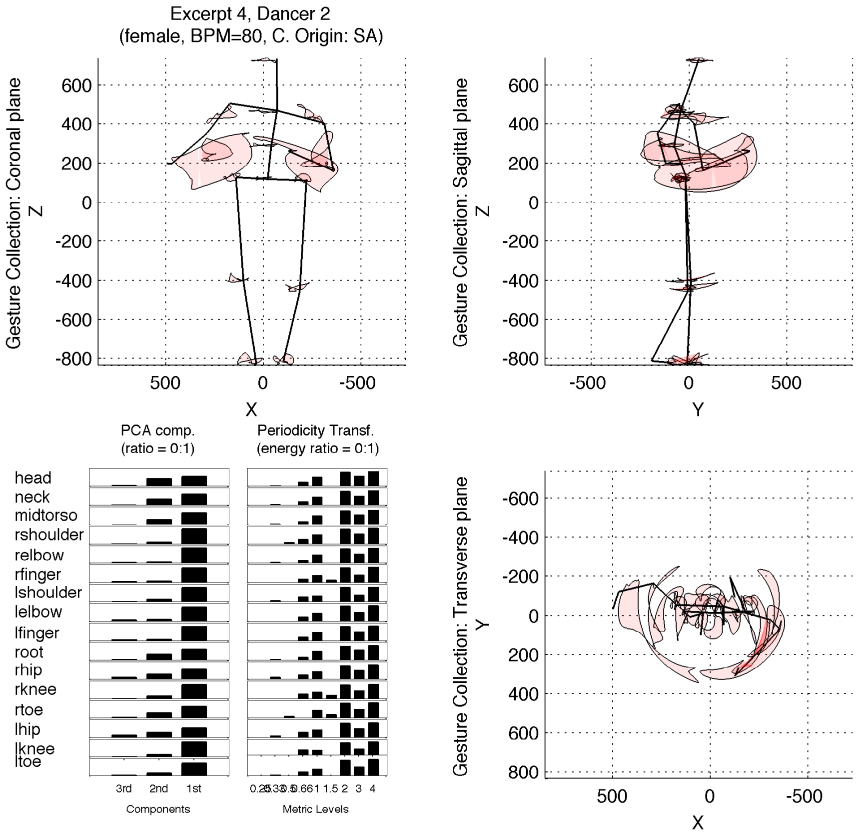


Figure B.7: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 4.

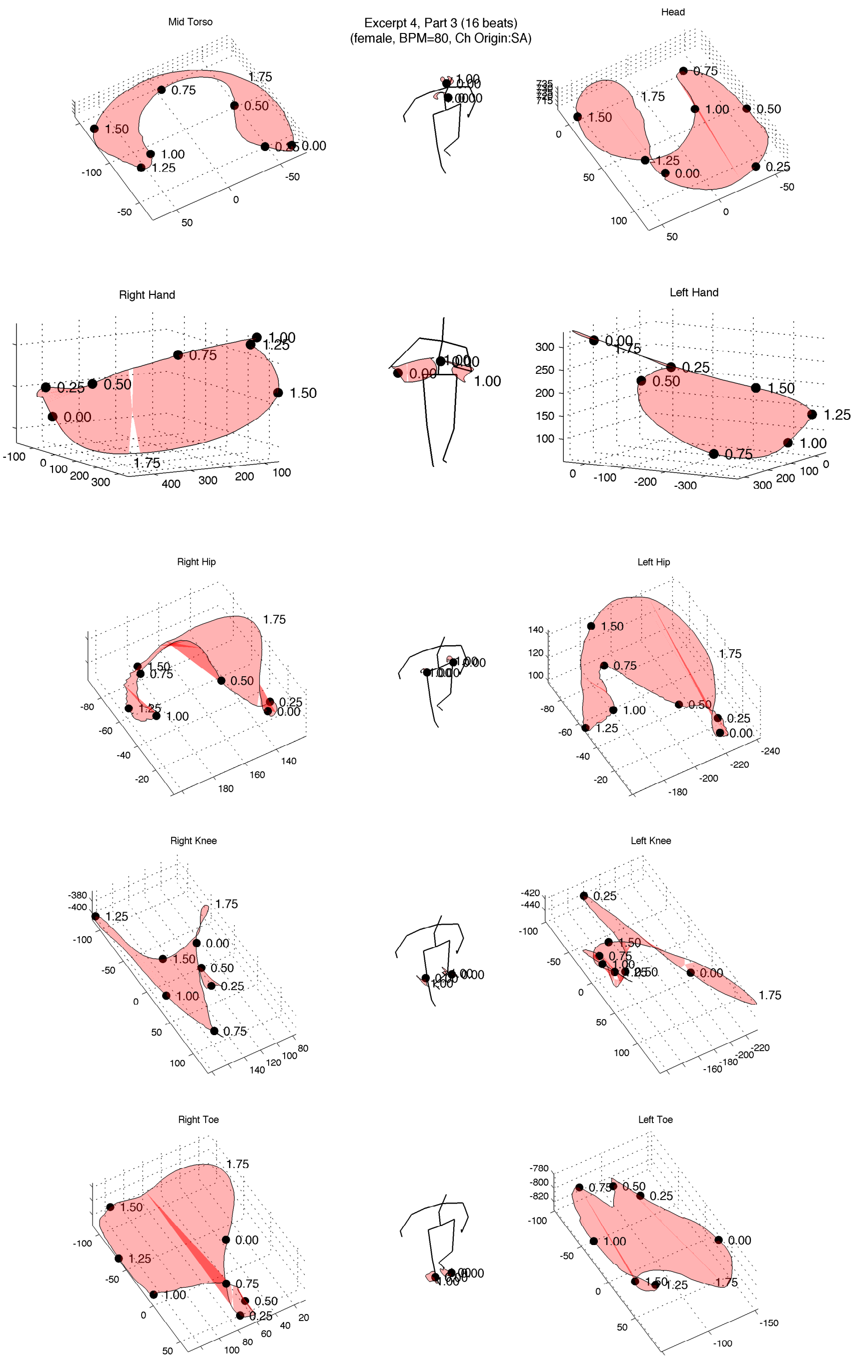


Figure B.8: Detailed view of the basic gestures for excerpt 4, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

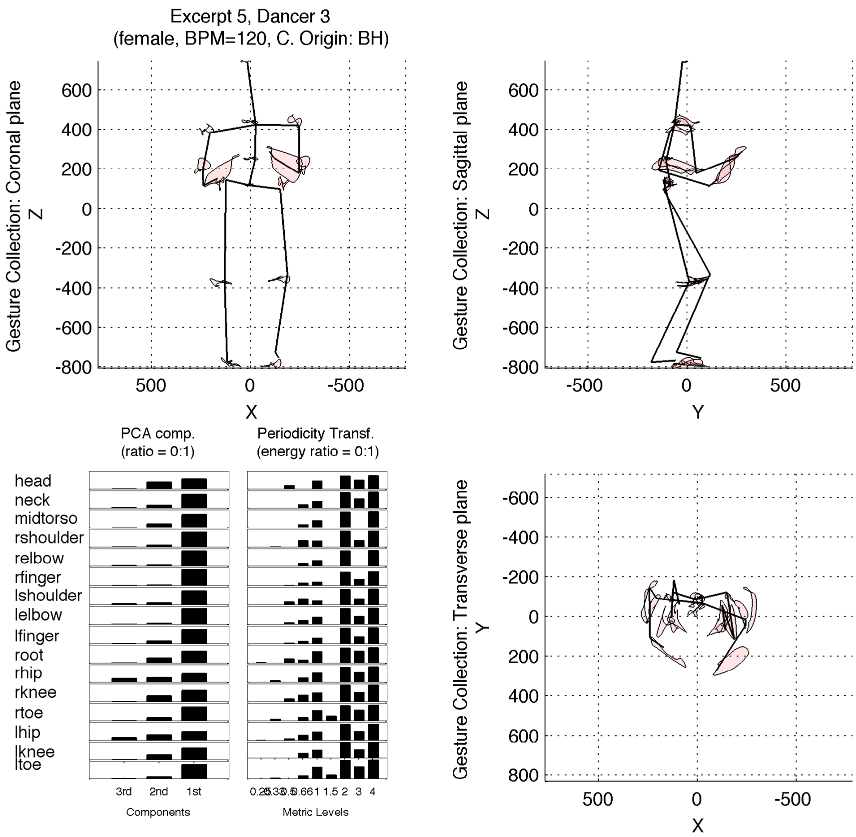


Figure B.9: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 5.

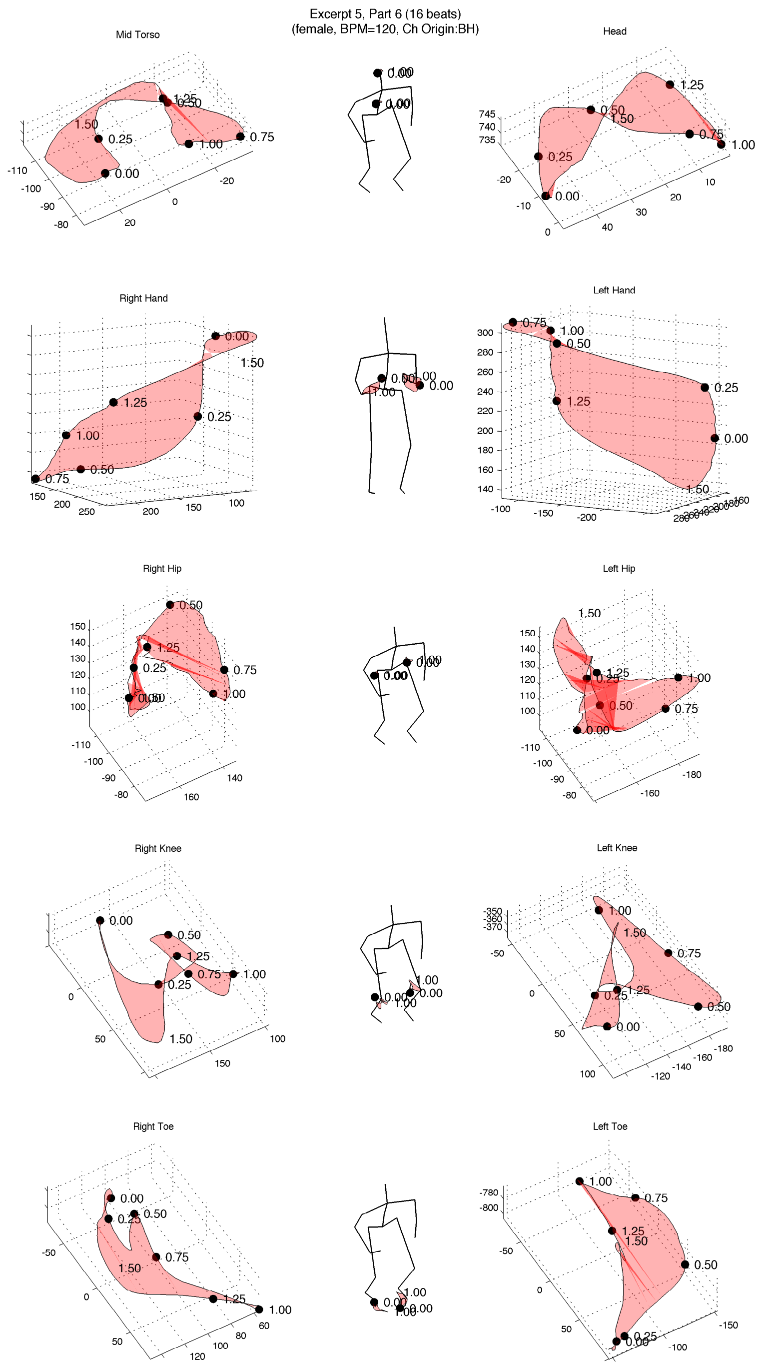


Figure B.10: Detailed view of the basic gestures for excerpt 5, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

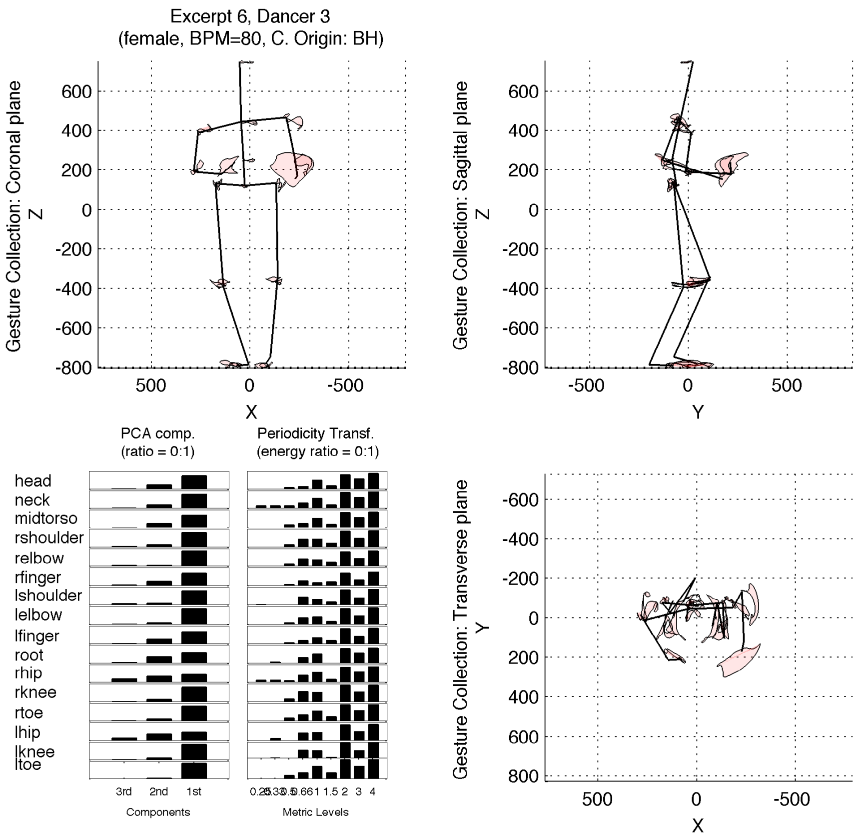


Figure B.11: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 6.

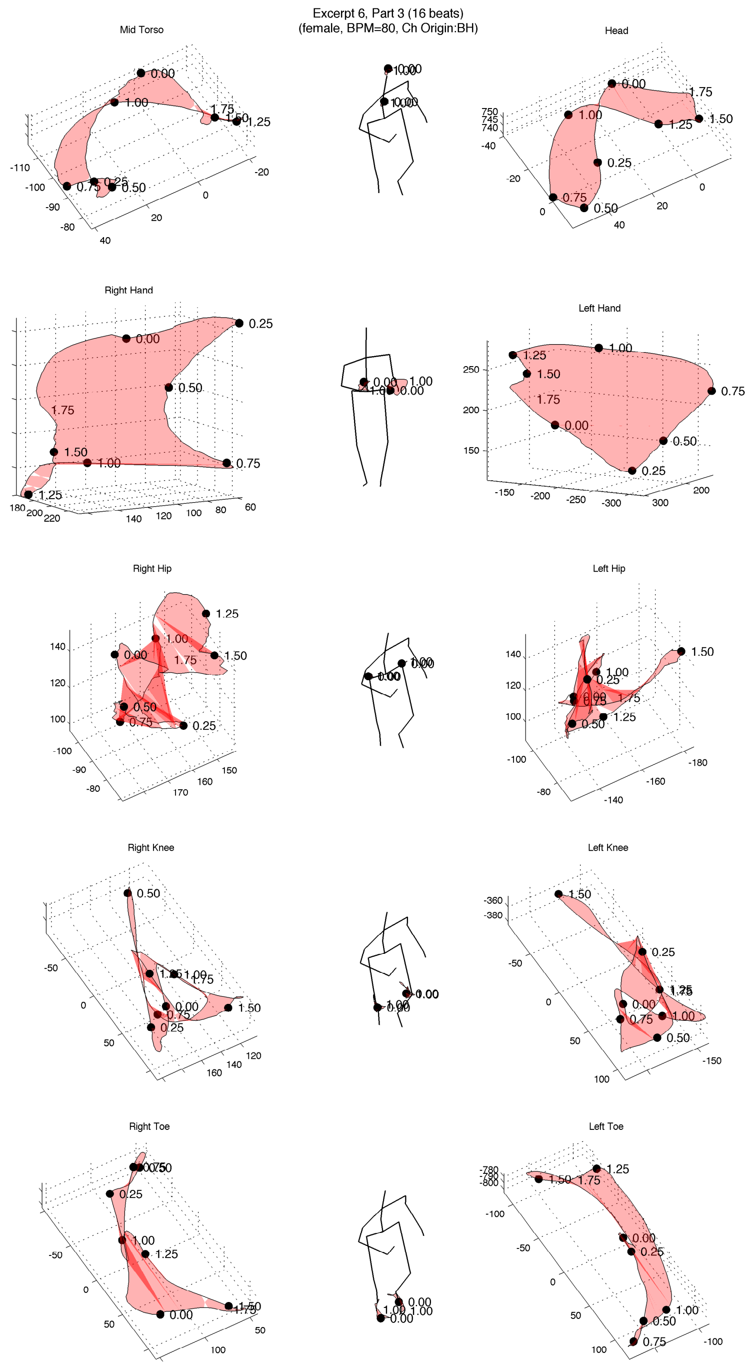


Figure B.12: Detailed view of the basic gestures for excerpt 6, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

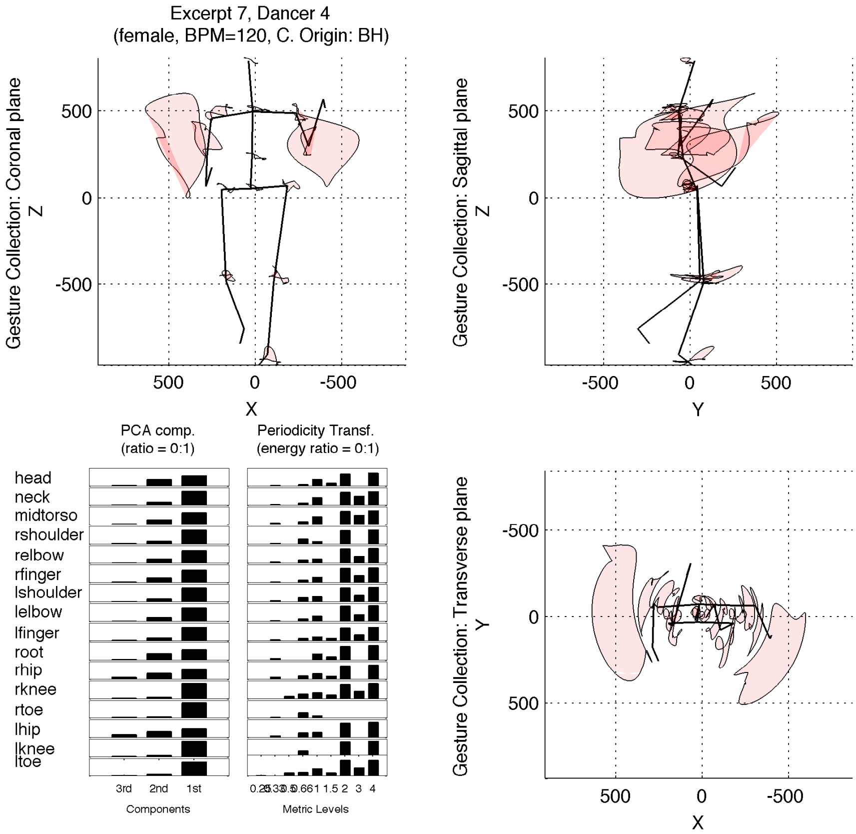


Figure B.13: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 7.

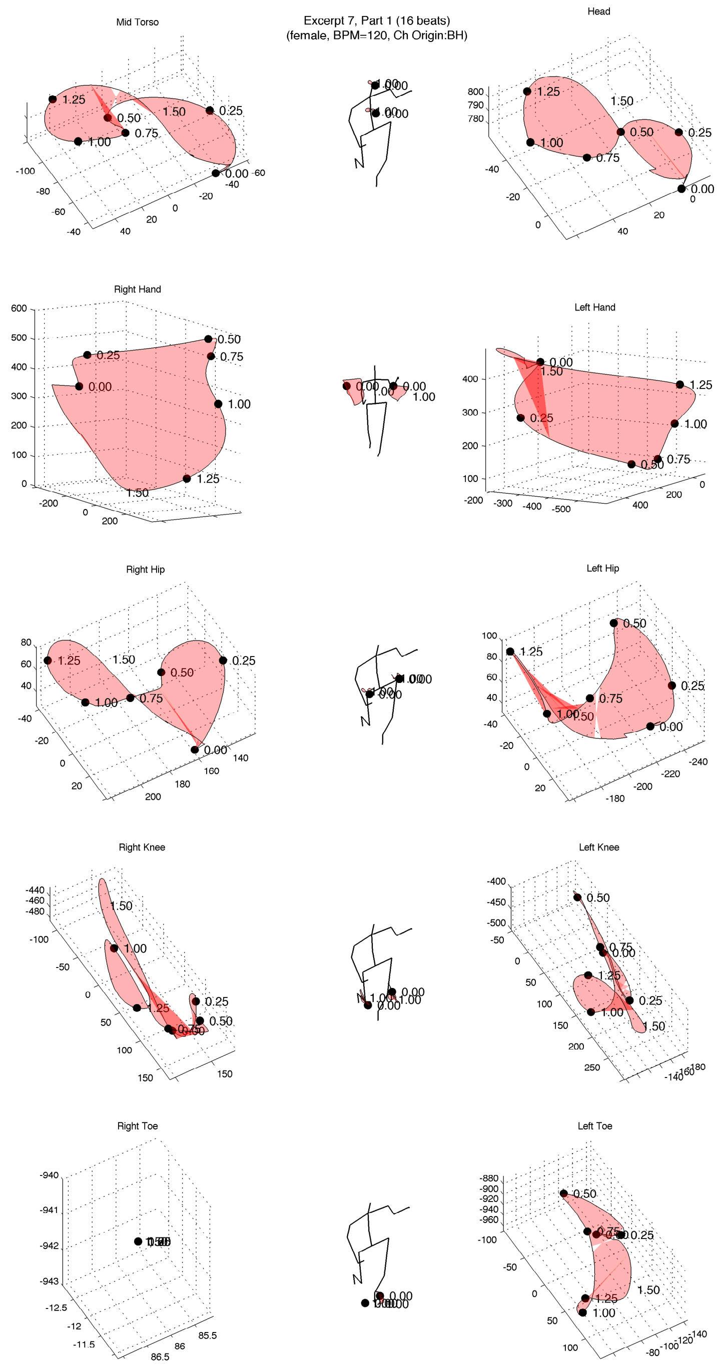


Figure B.14: Detailed view of the basic gestures for excerpt 7, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

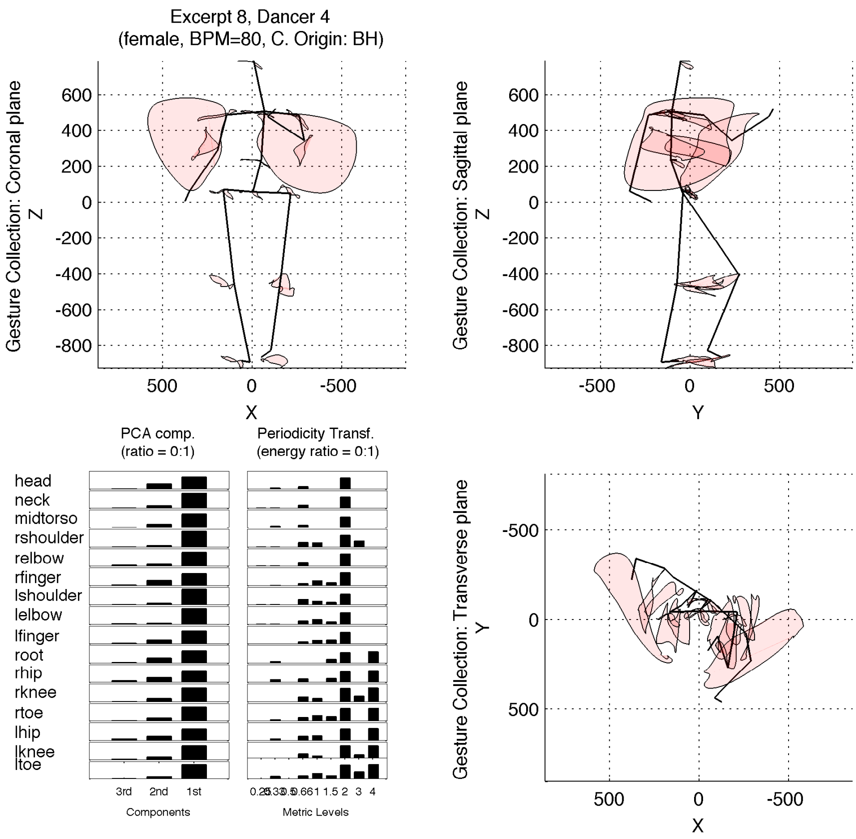


Figure B.15: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 8.

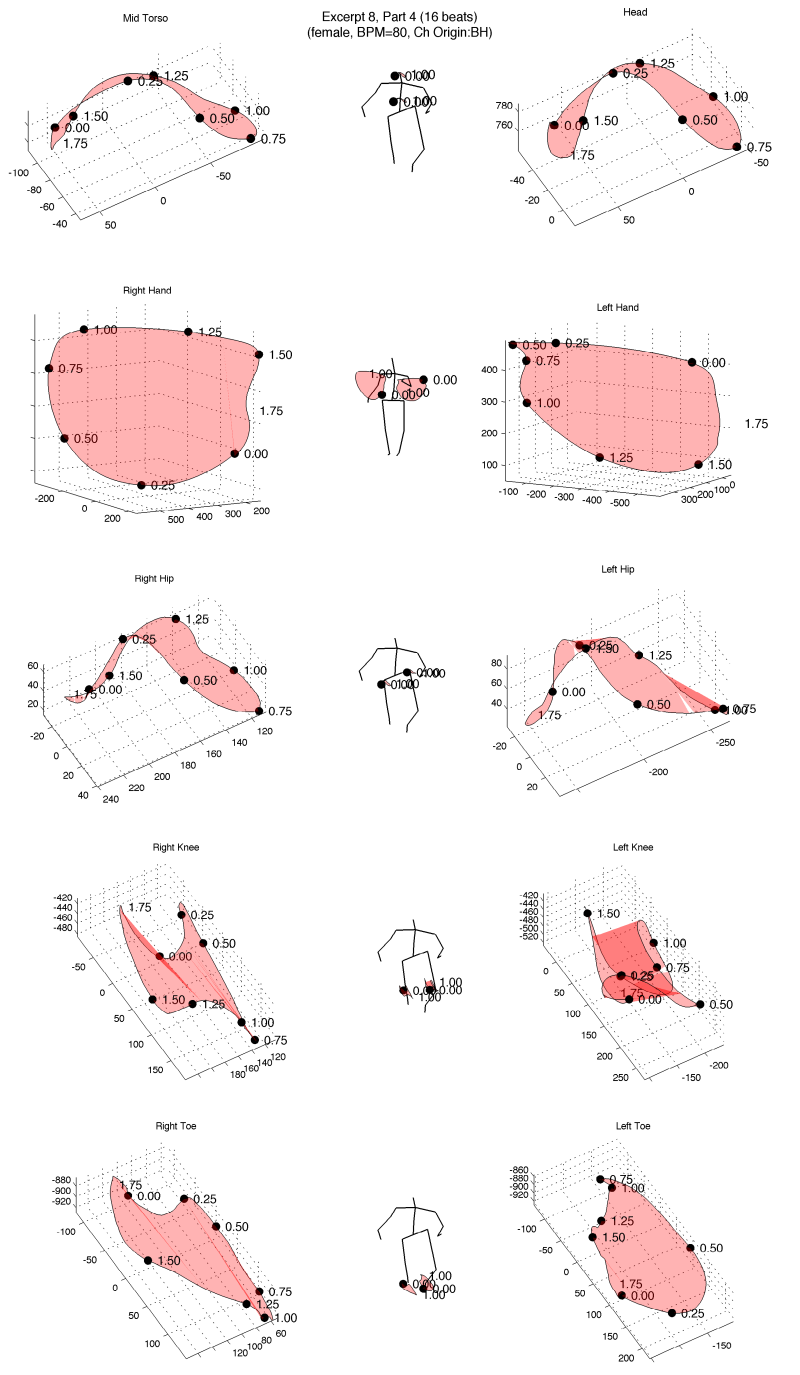


Figure B.16: Detailed view of the basic gestures for excerpt 8, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

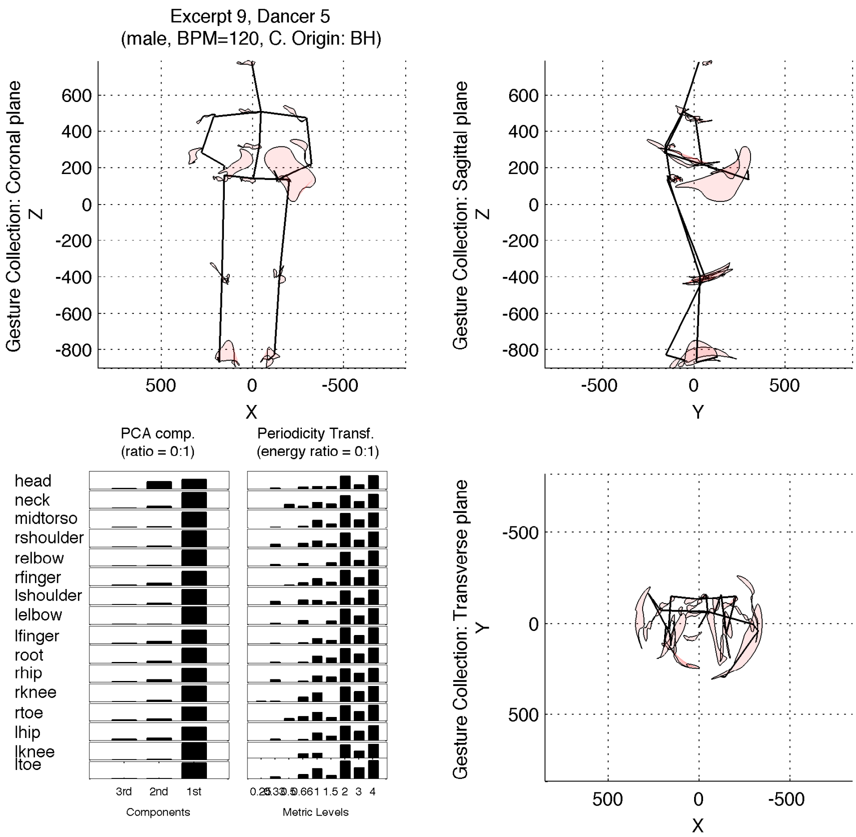


Figure B.17: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 9.

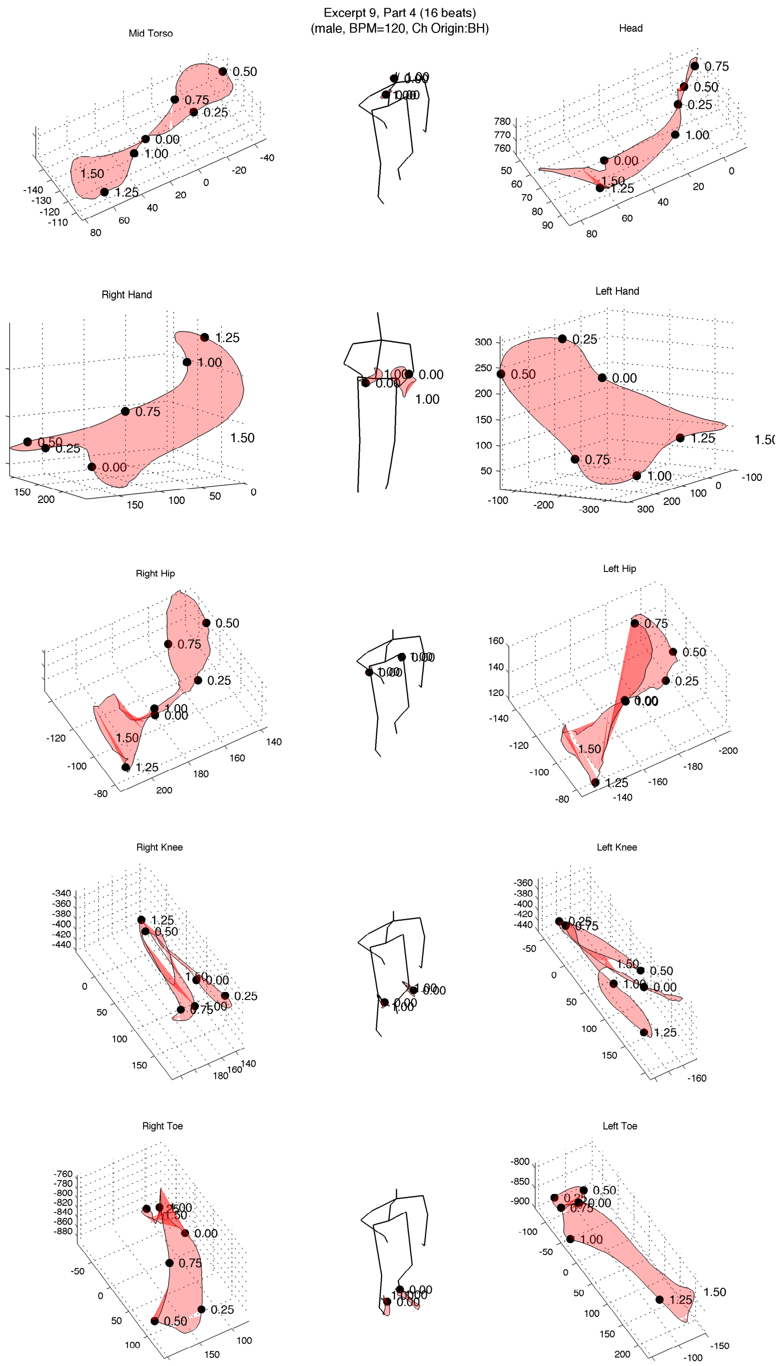


Figure B.18: Detailed view of the basic gestures for excerpt 9, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

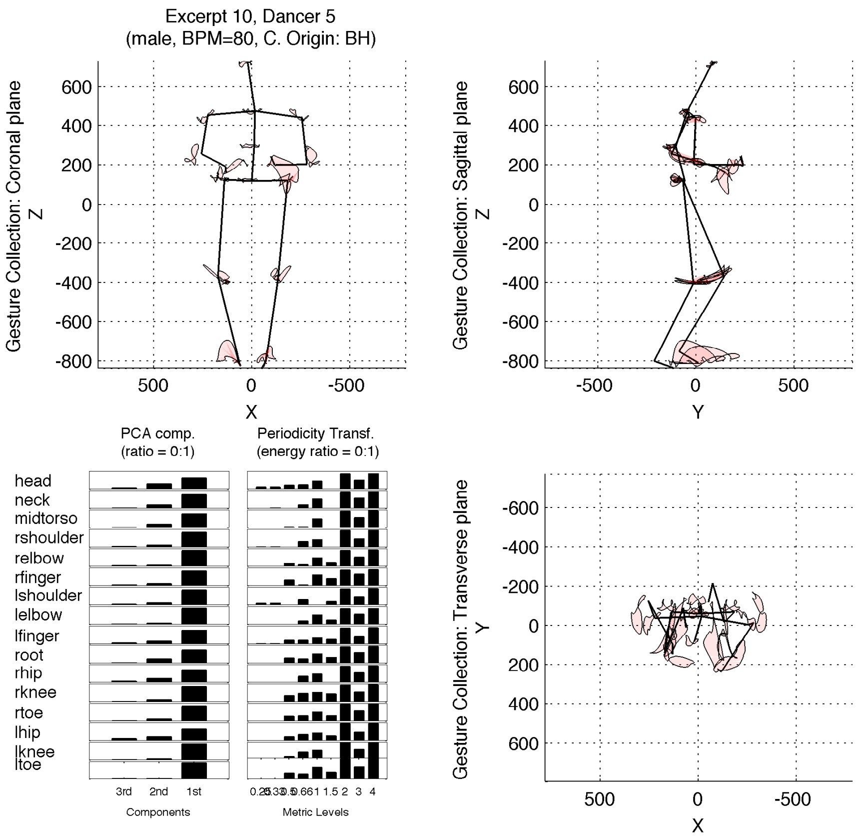


Figure B.19: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 10.

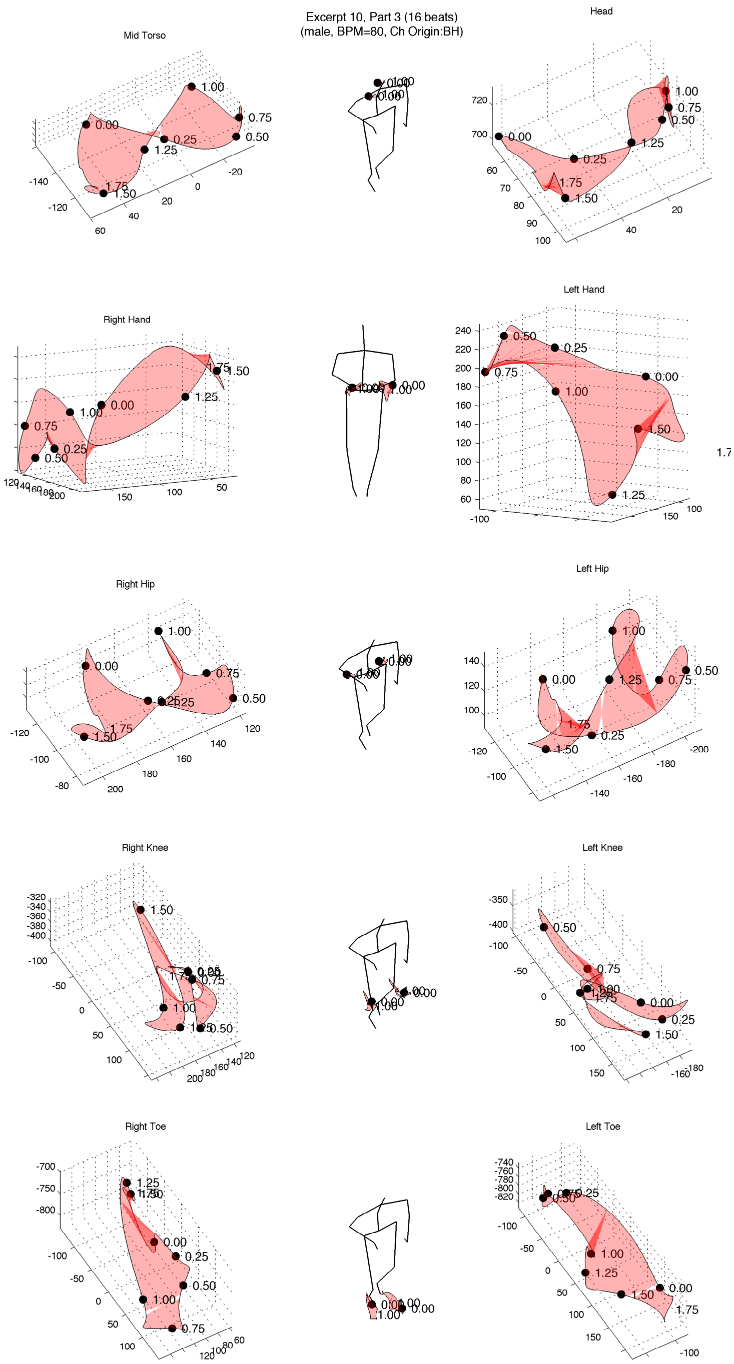


Figure B.20: Detailed view of the basic gestures for excerpt 10, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

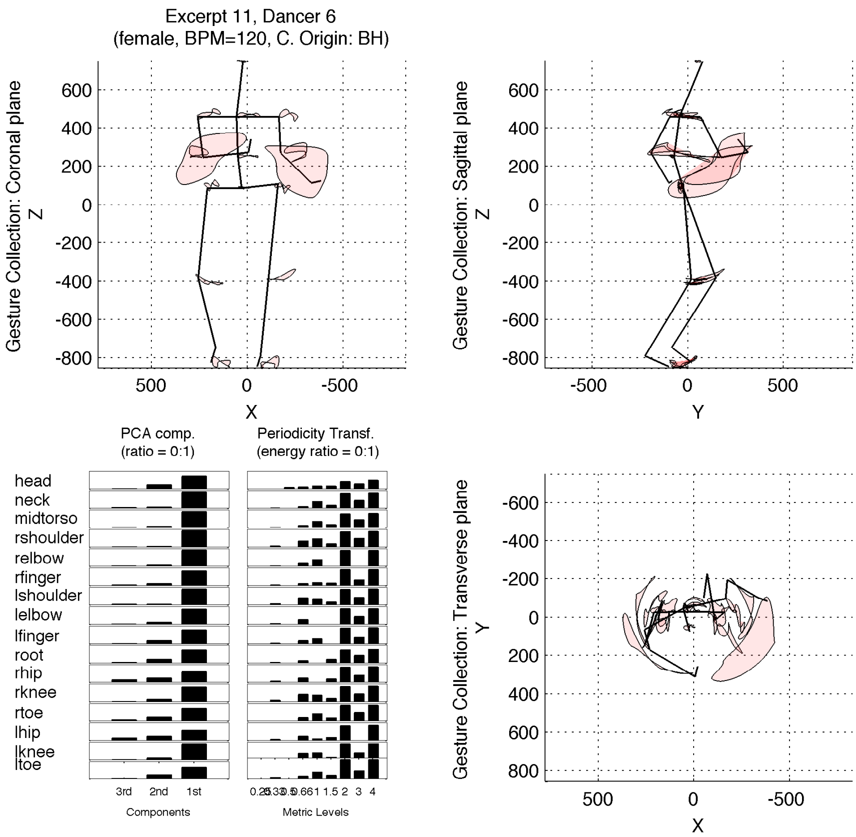


Figure B.21: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 11.

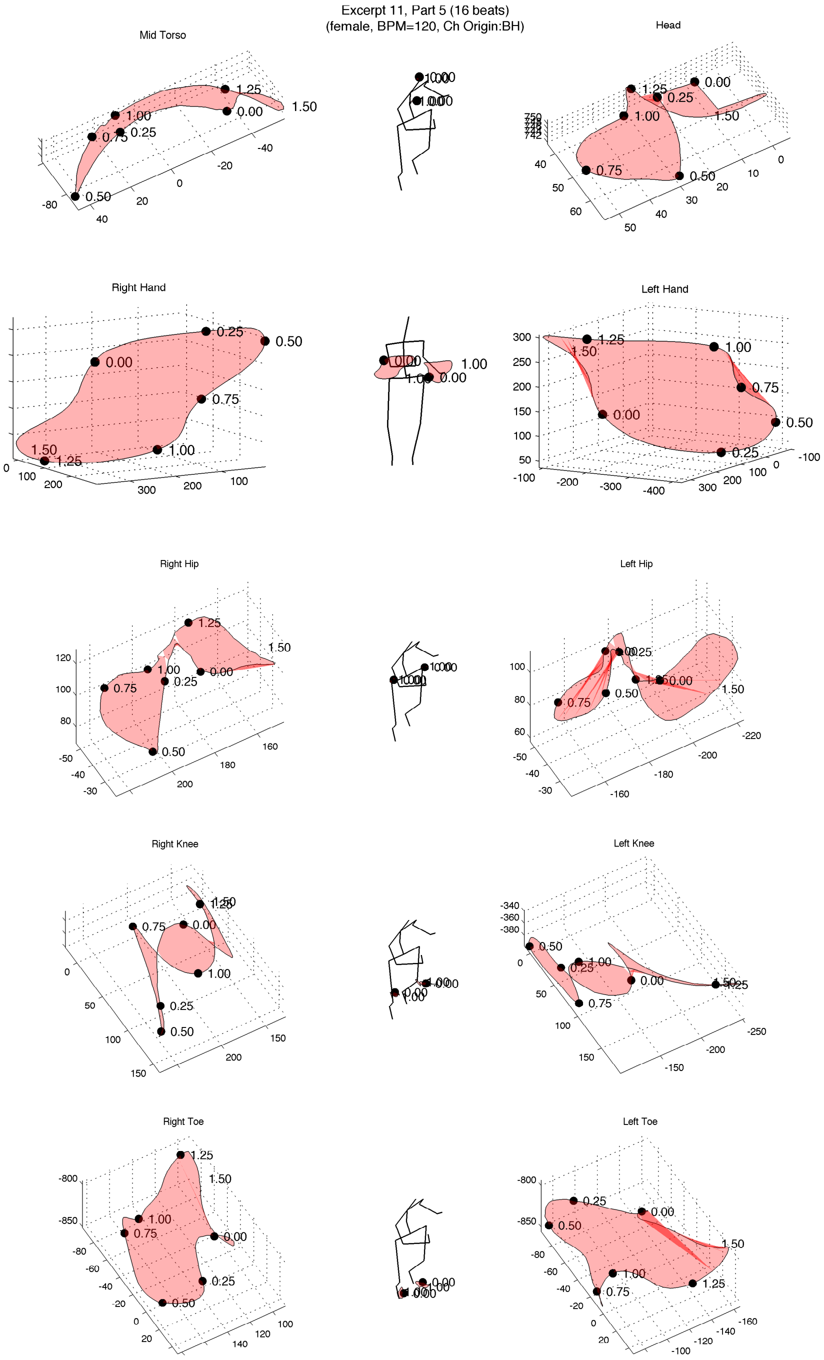


Figure B.22: Detailed view of the basic gestures for excerpt 11, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

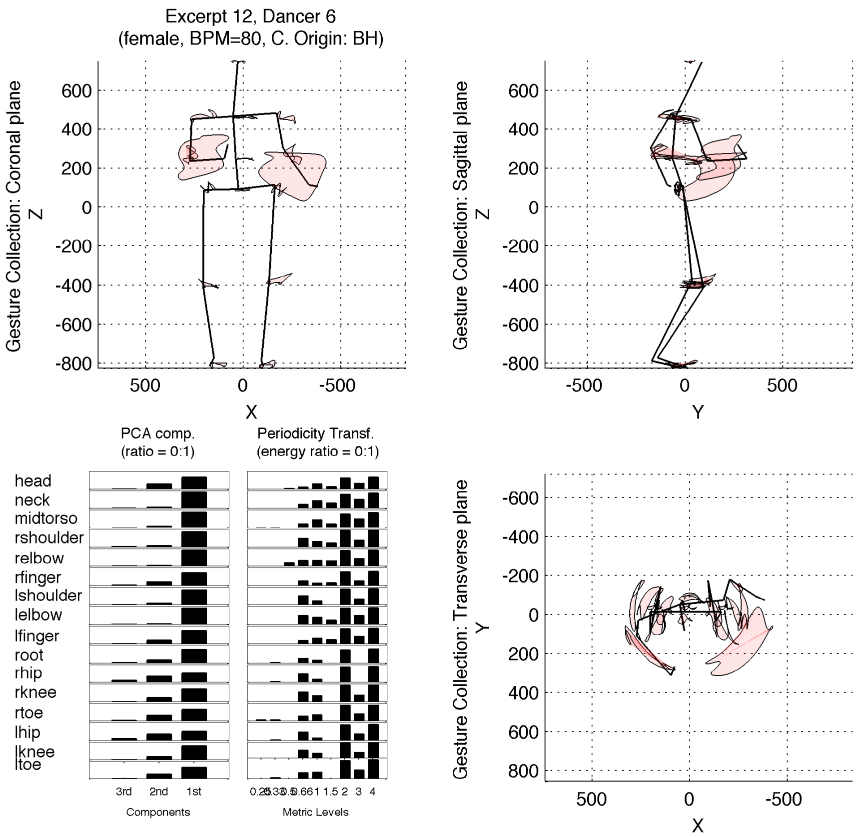


Figure B.23: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 12.

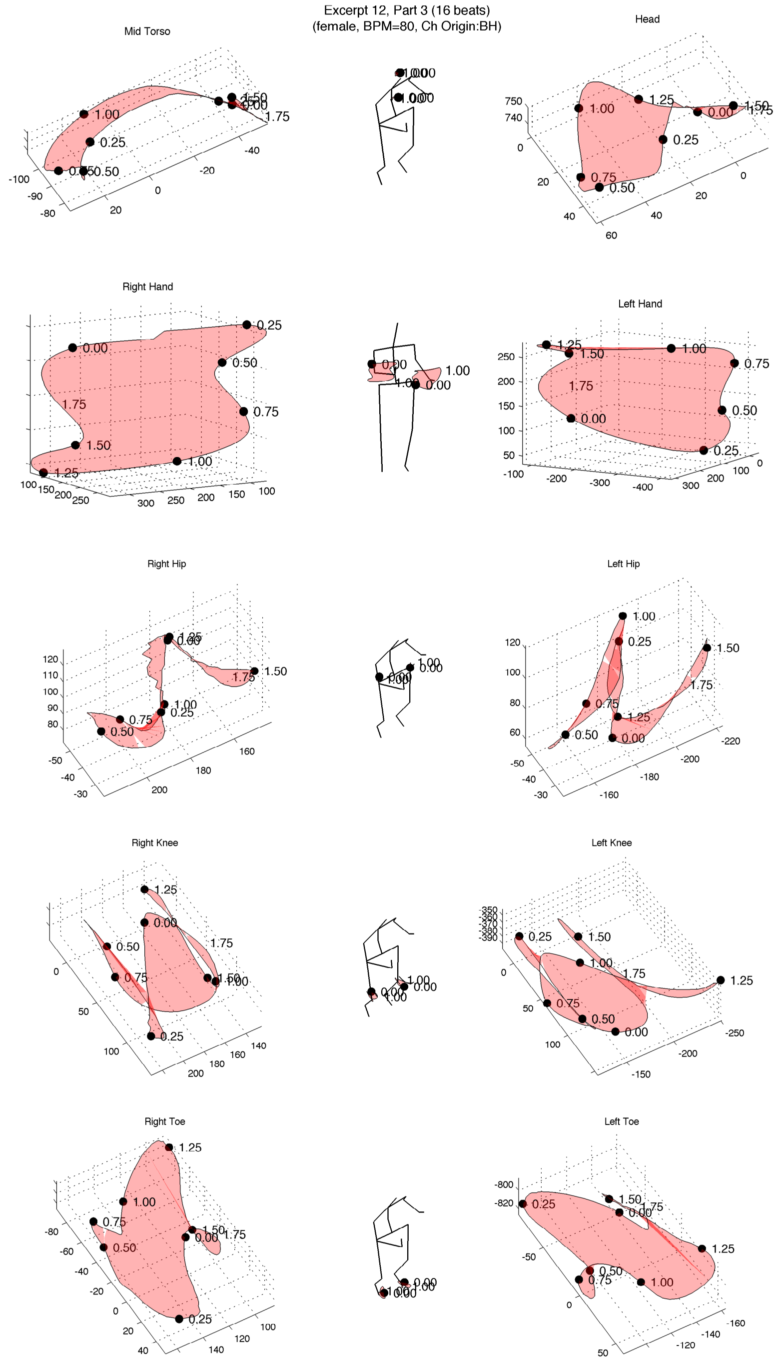


Figure B.24: Detailed view of the basic gestures for excerpt 12, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

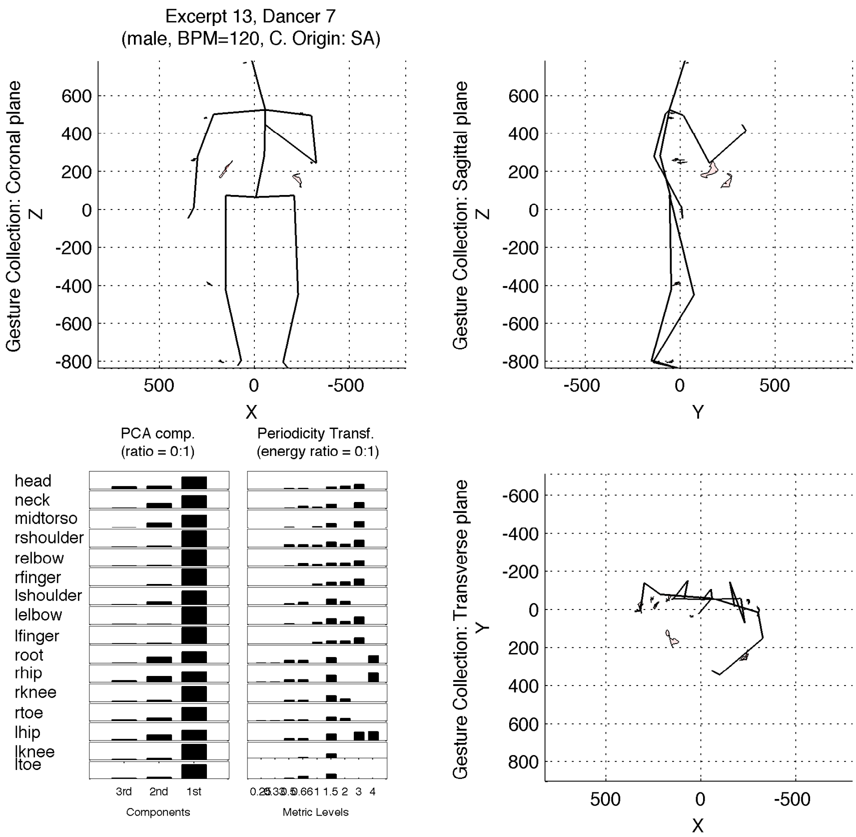


Figure B.25: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 13.

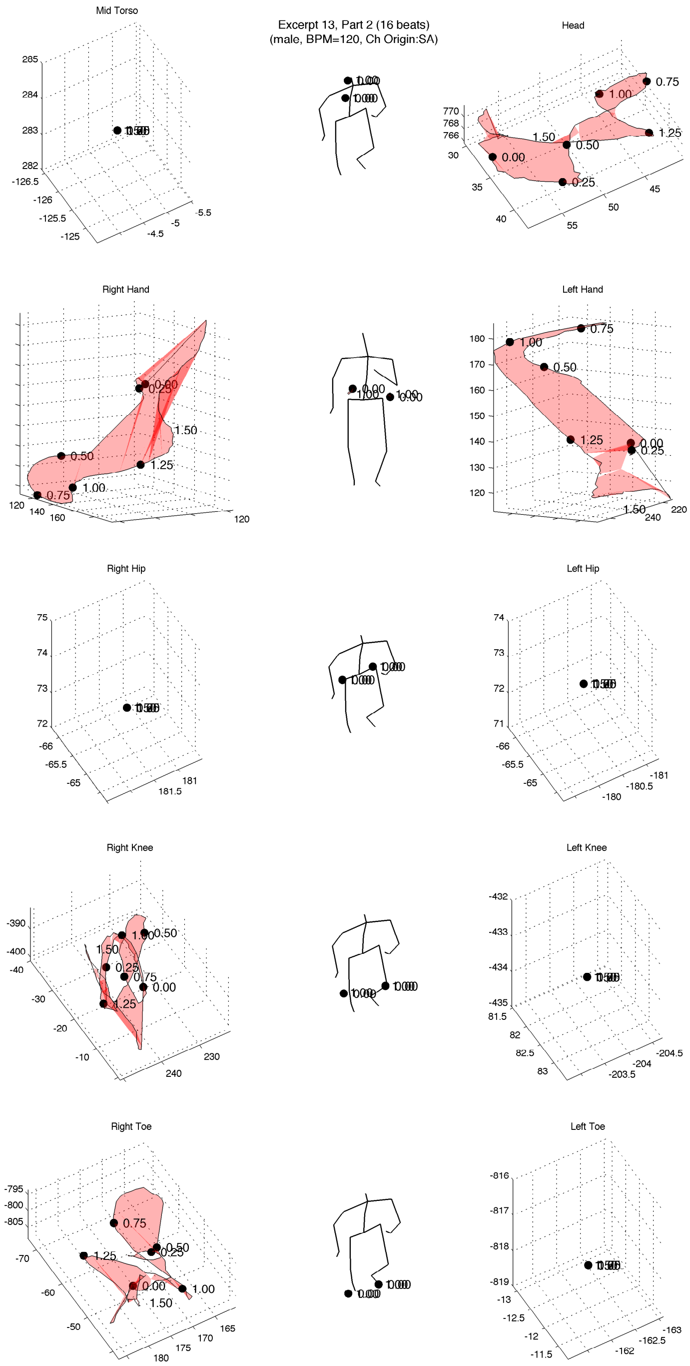


Figure B.26: Detailed view of the basic gestures for excerpt 13, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

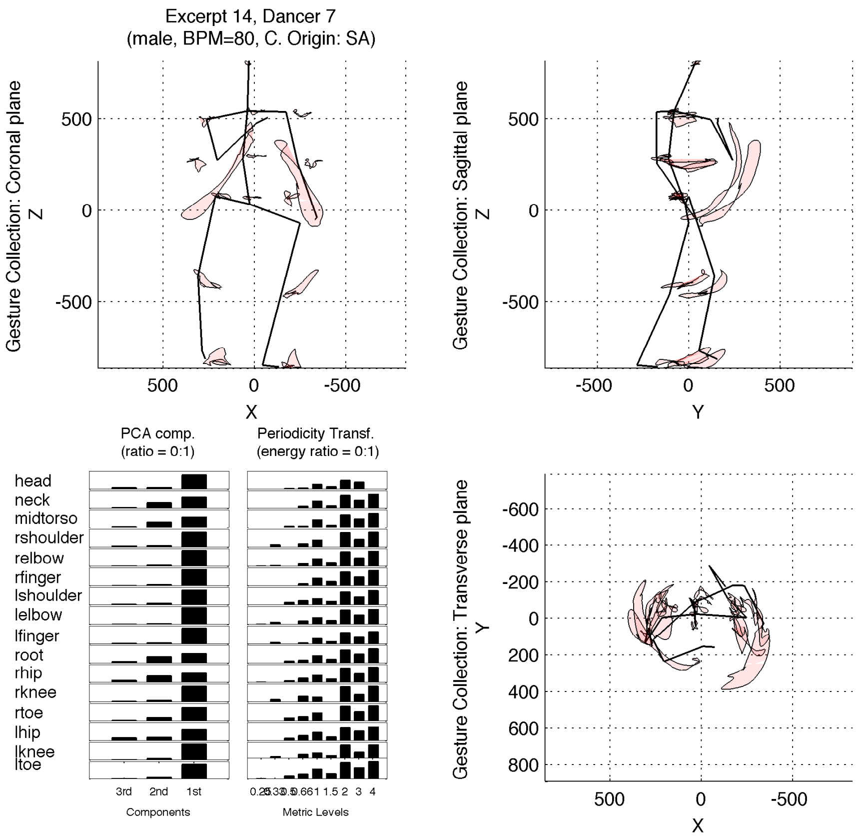


Figure B.27: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 14.

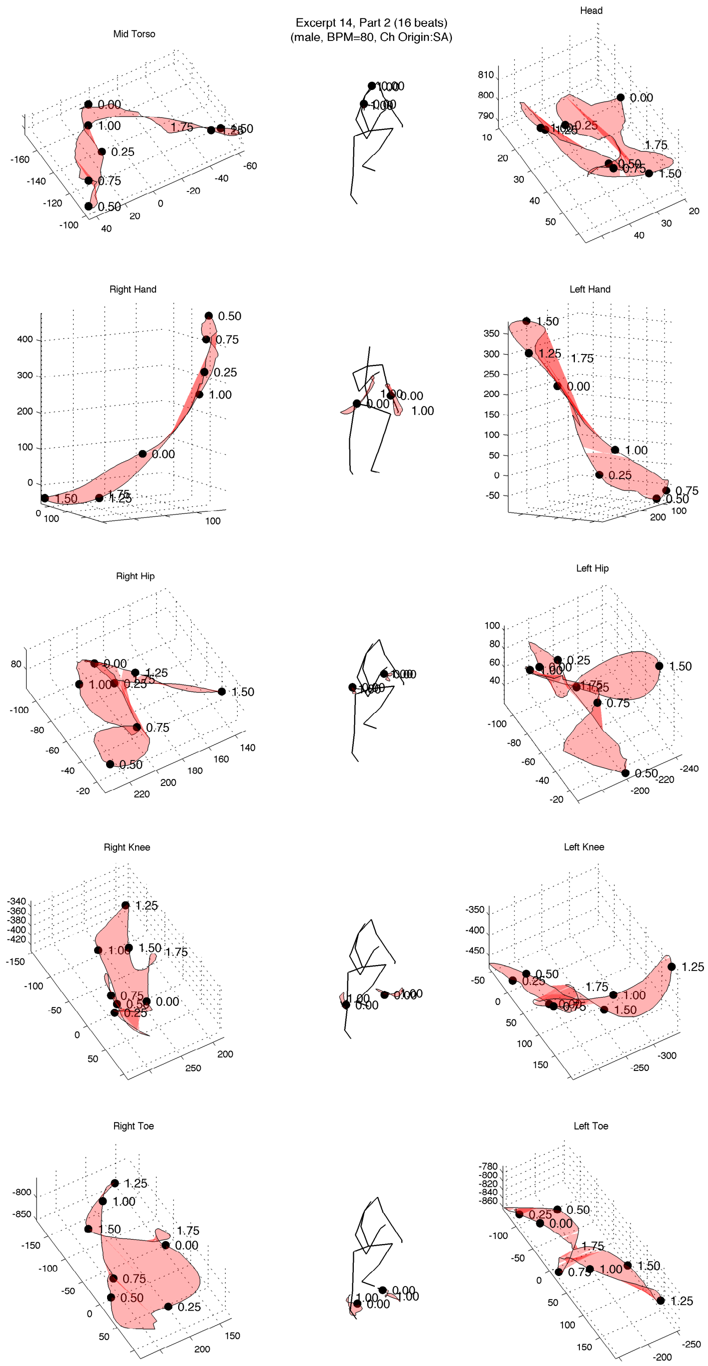


Figure B.28: Detailed view of the basic gestures for excerpt 14, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

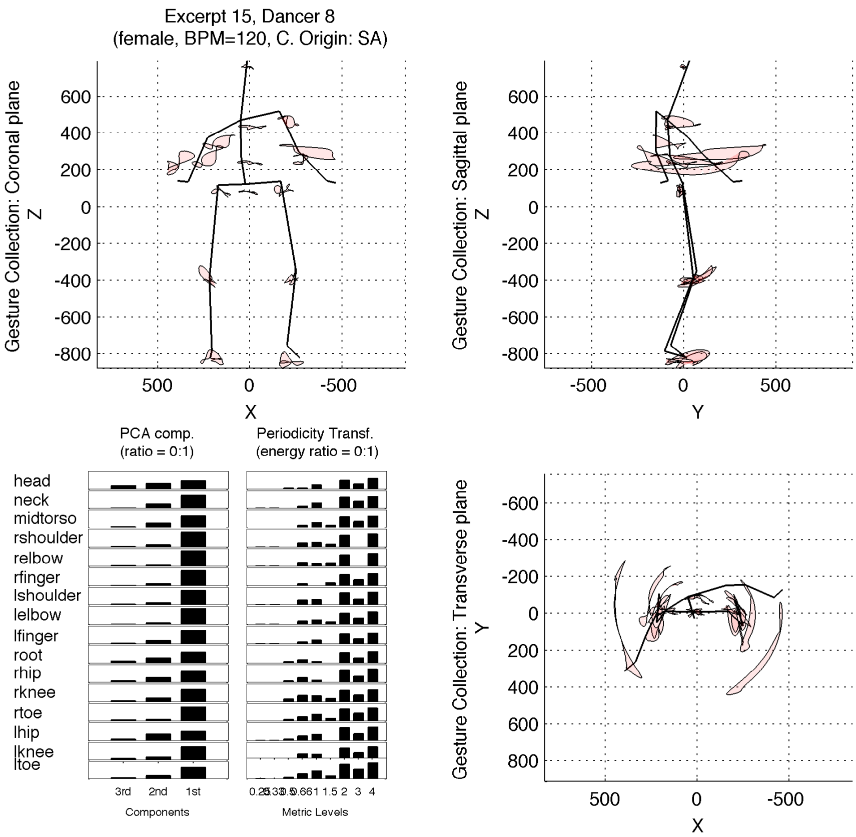


Figure B.29: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 15.

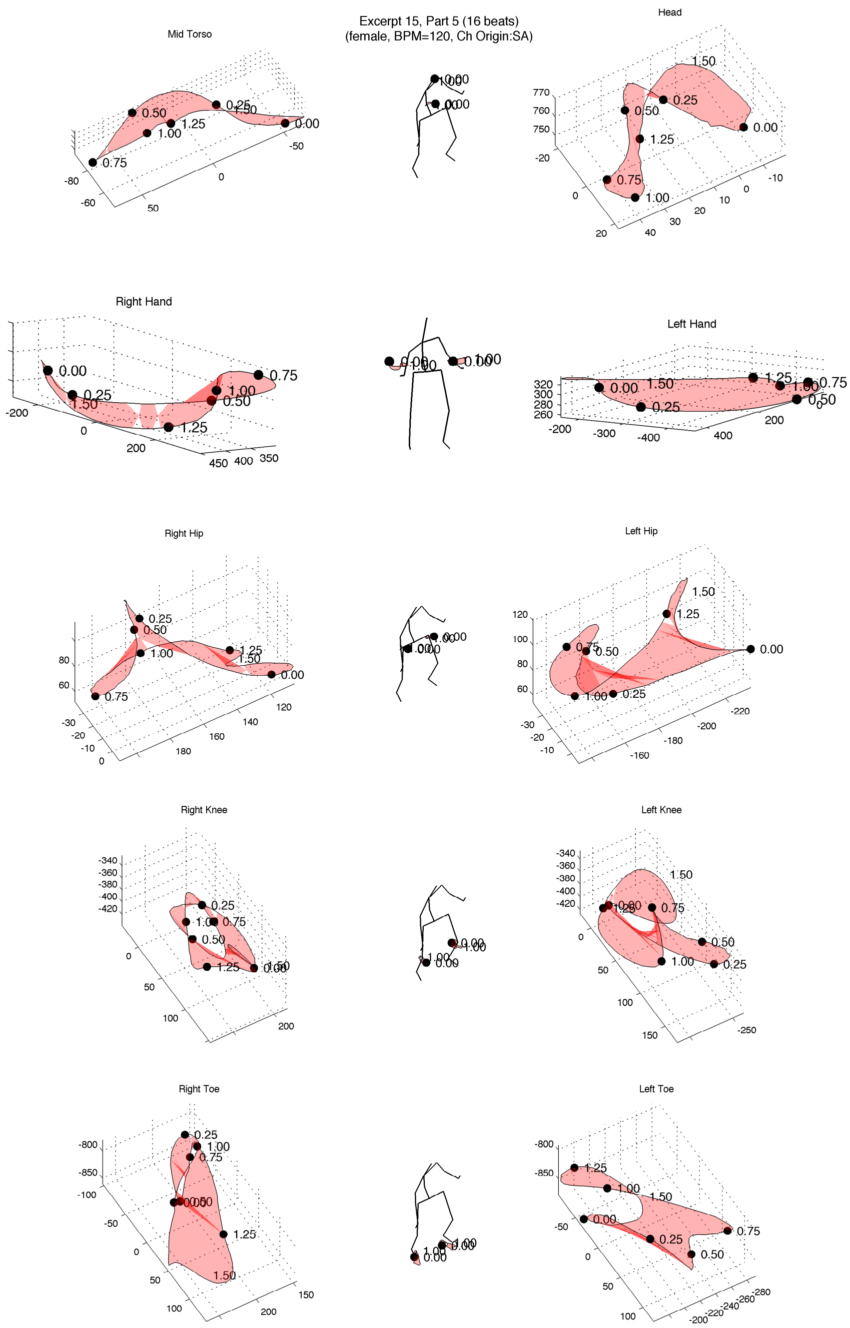


Figure B.30: Detailed view of the basic gestures for excerpt 15, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

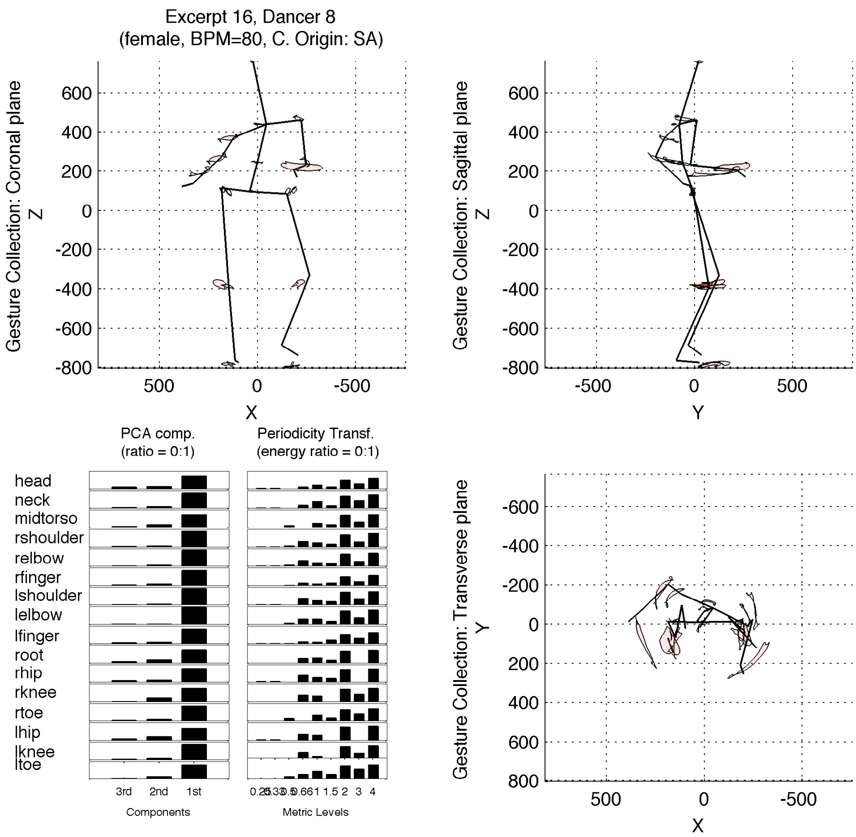


Figure B.31: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 16.

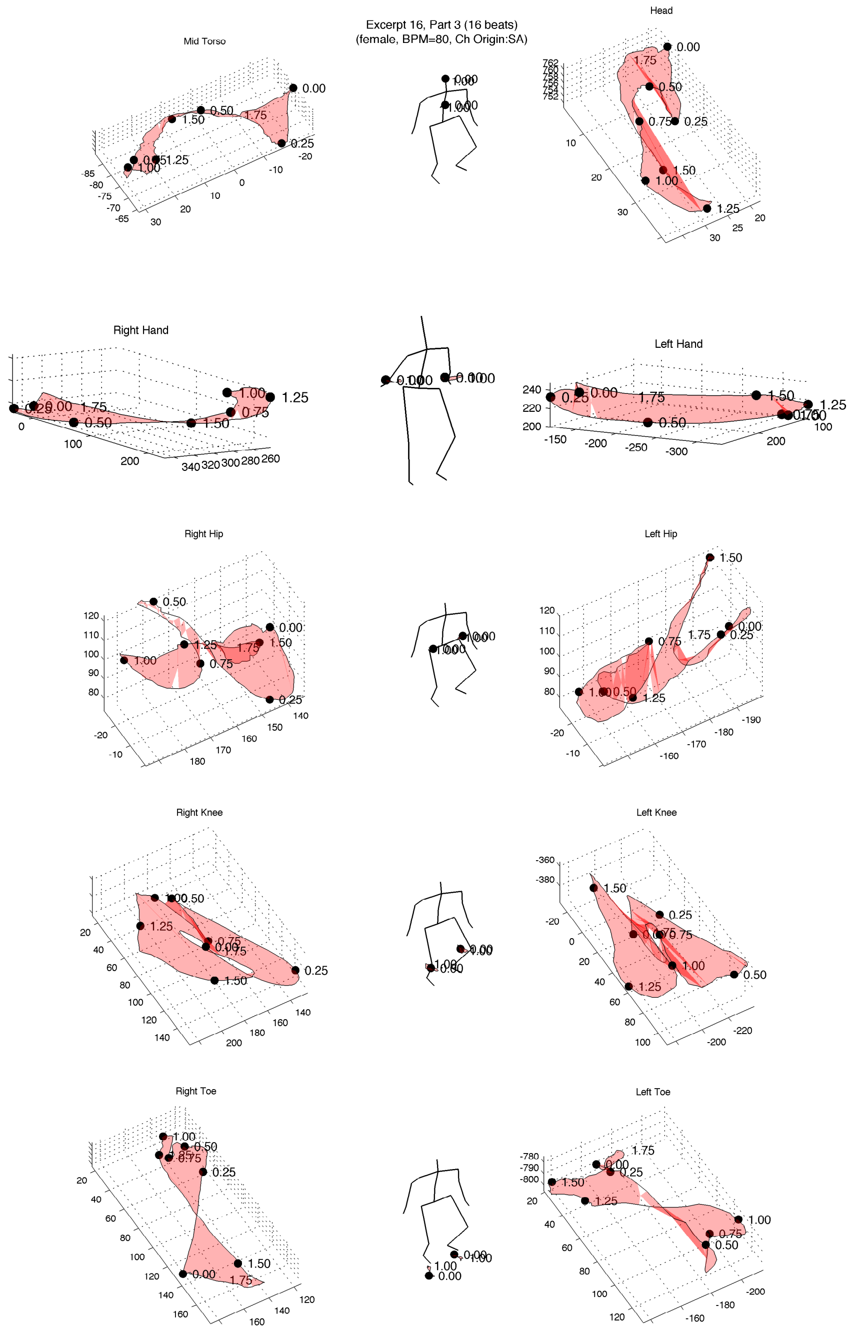


Figure B.32: Detailed view of the basic gestures for excerpt 16, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

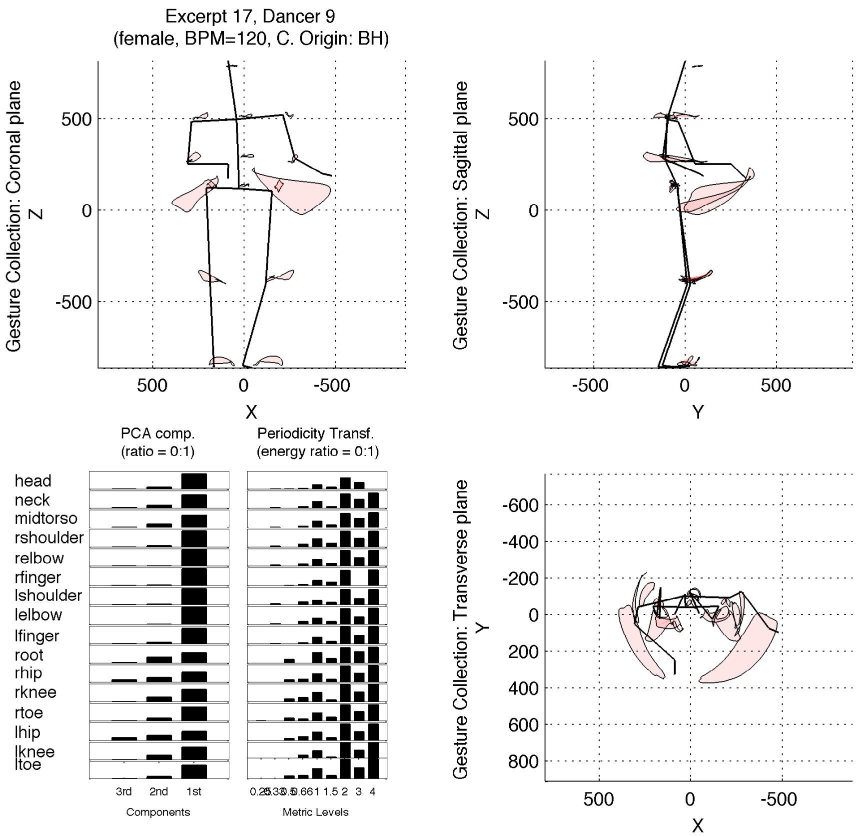


Figure B.33: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 17.

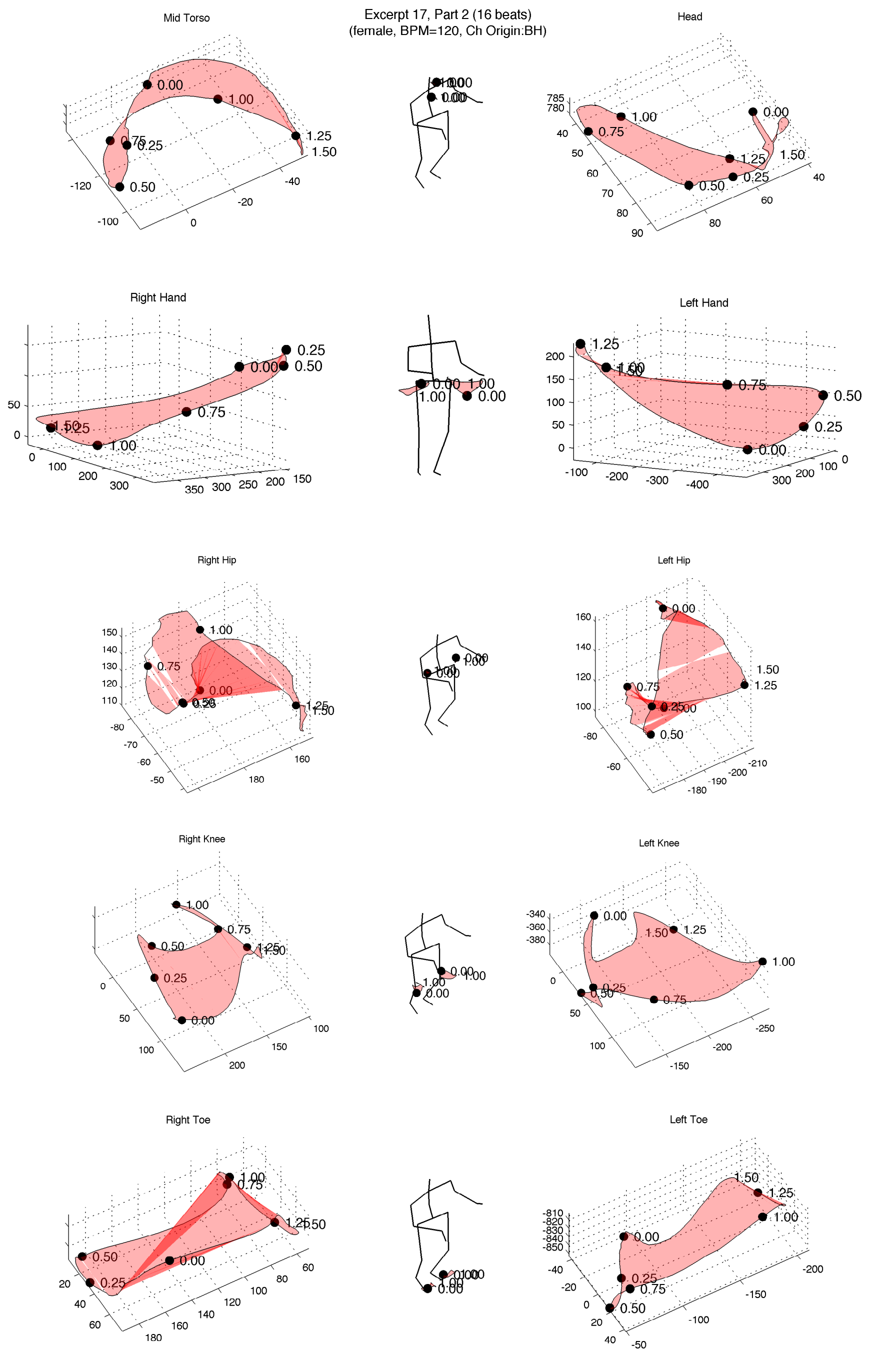


Figure B.34: Detailed view of the basic gestures for excerpt 17, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

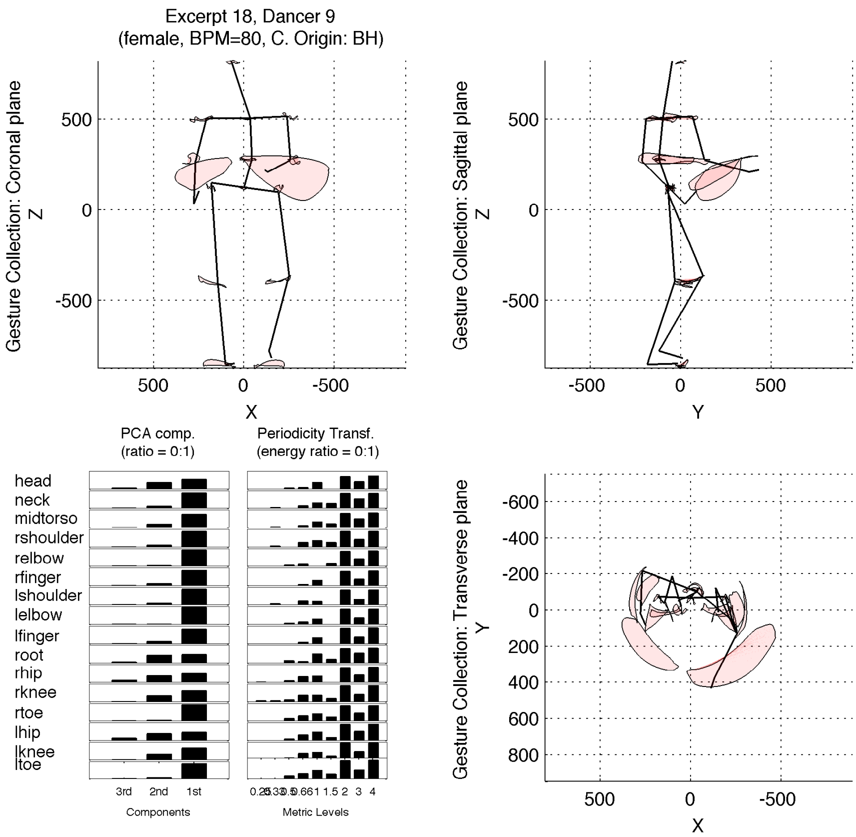


Figure B.35: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 18.

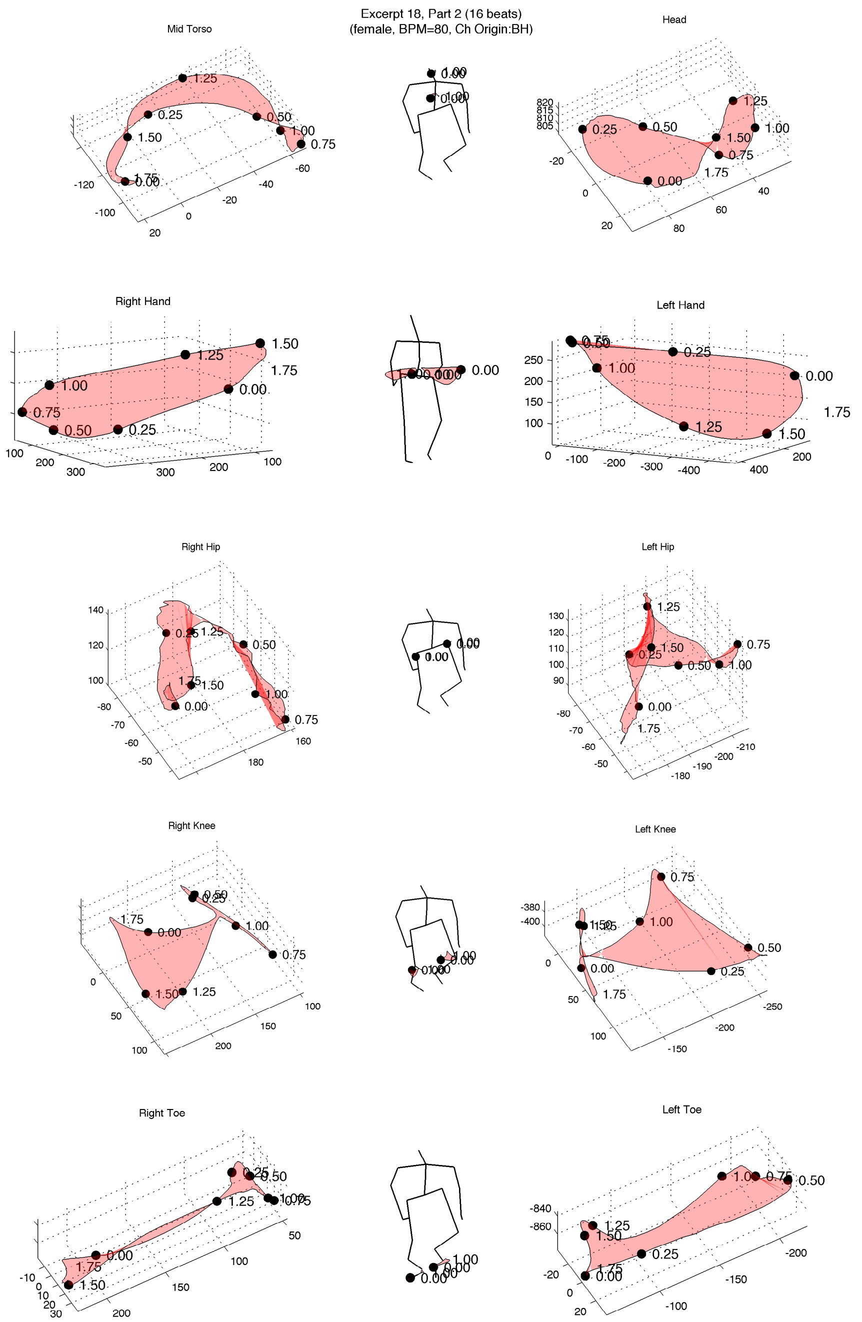


Figure B.36: Detailed view of the basic gestures for excerpt 18, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

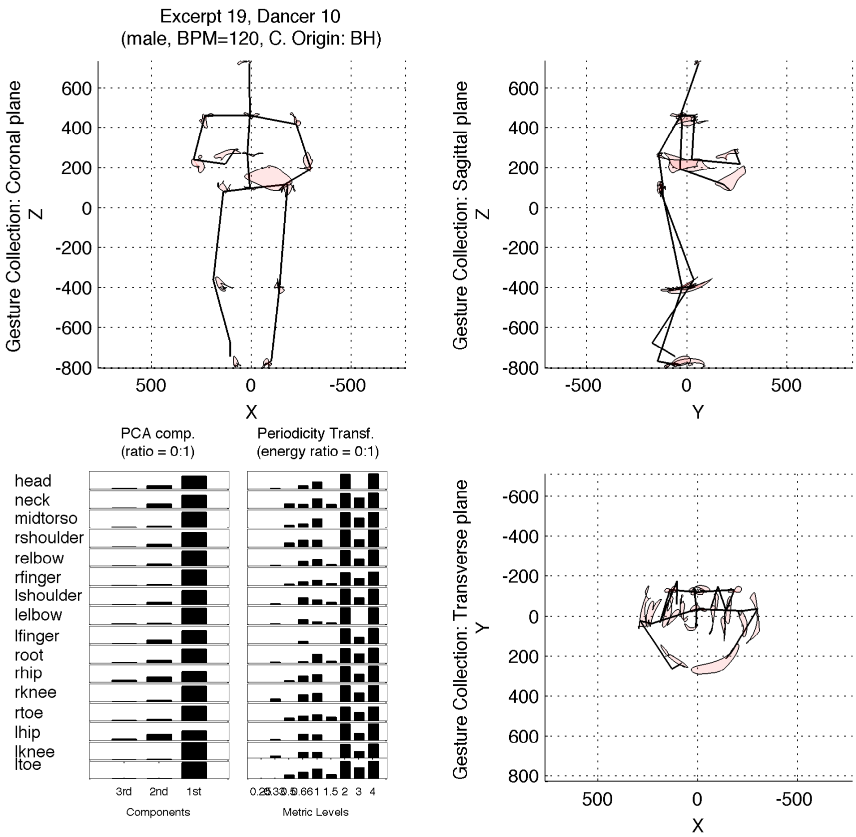


Figure B.37: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 19.

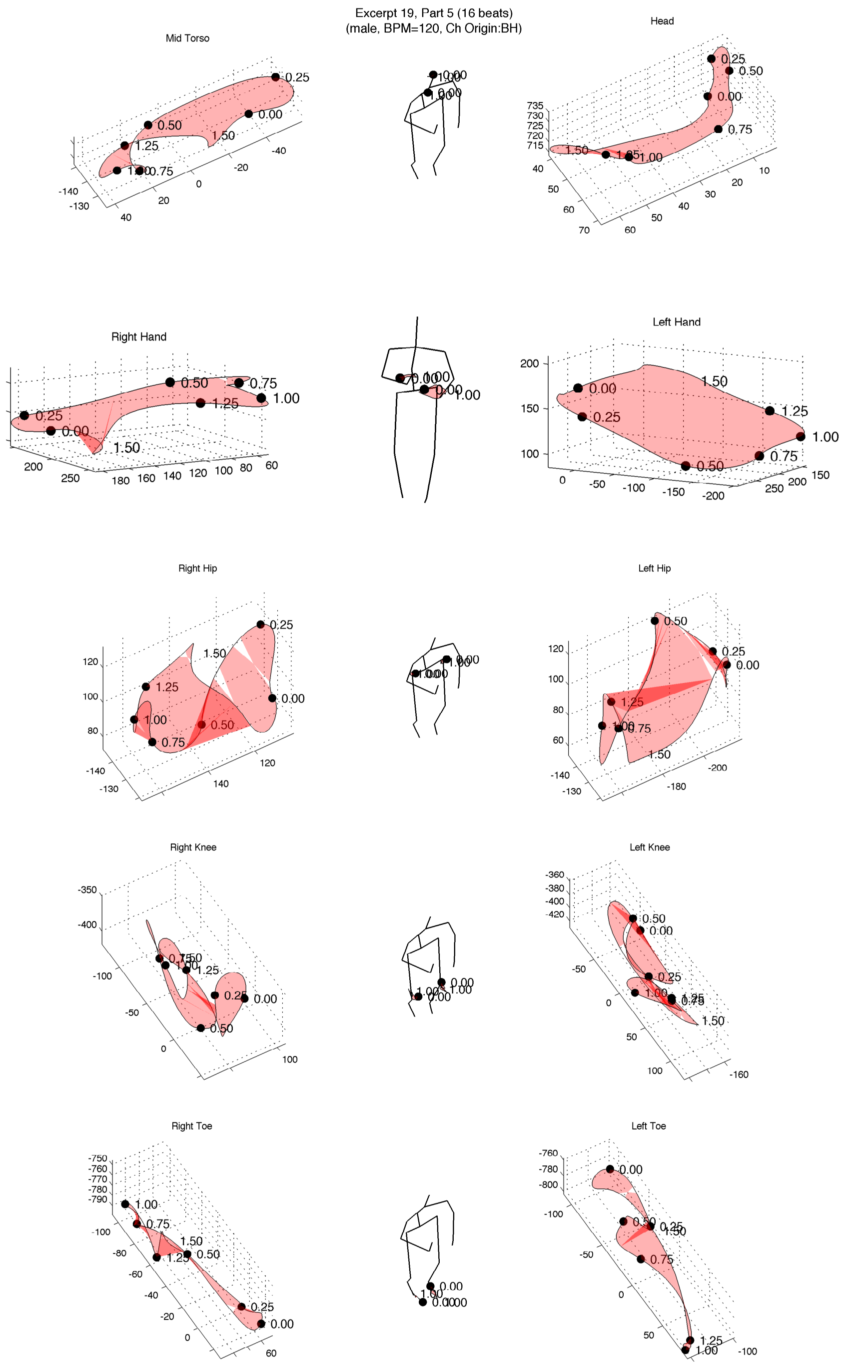


Figure B.38: Detailed view of the basic gestures for excerpt 19, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

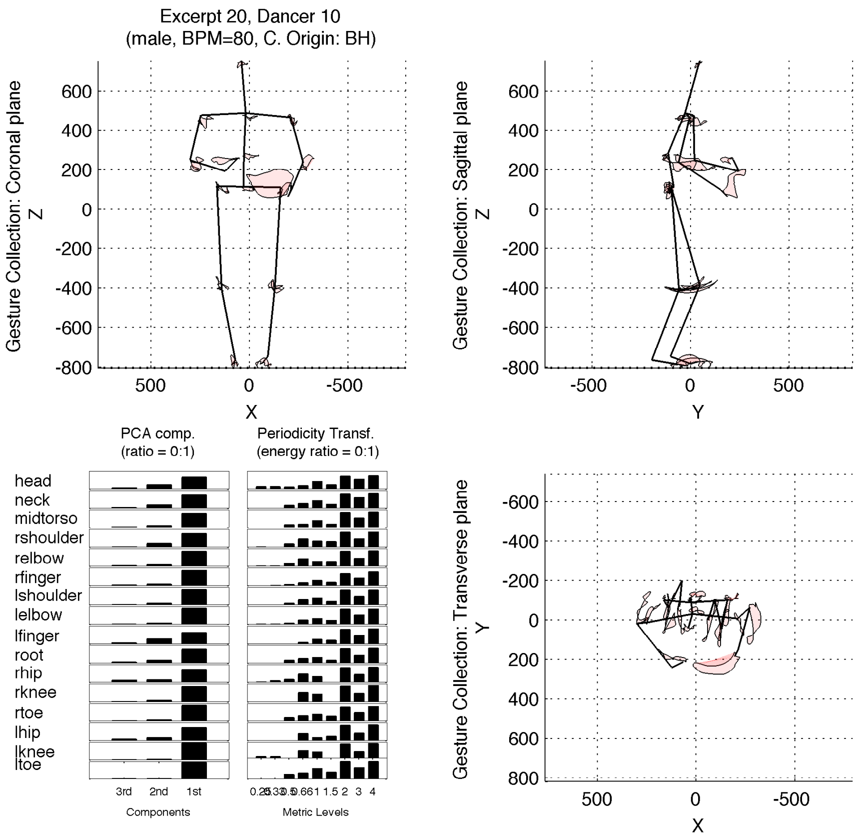


Figure B.39: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 20.

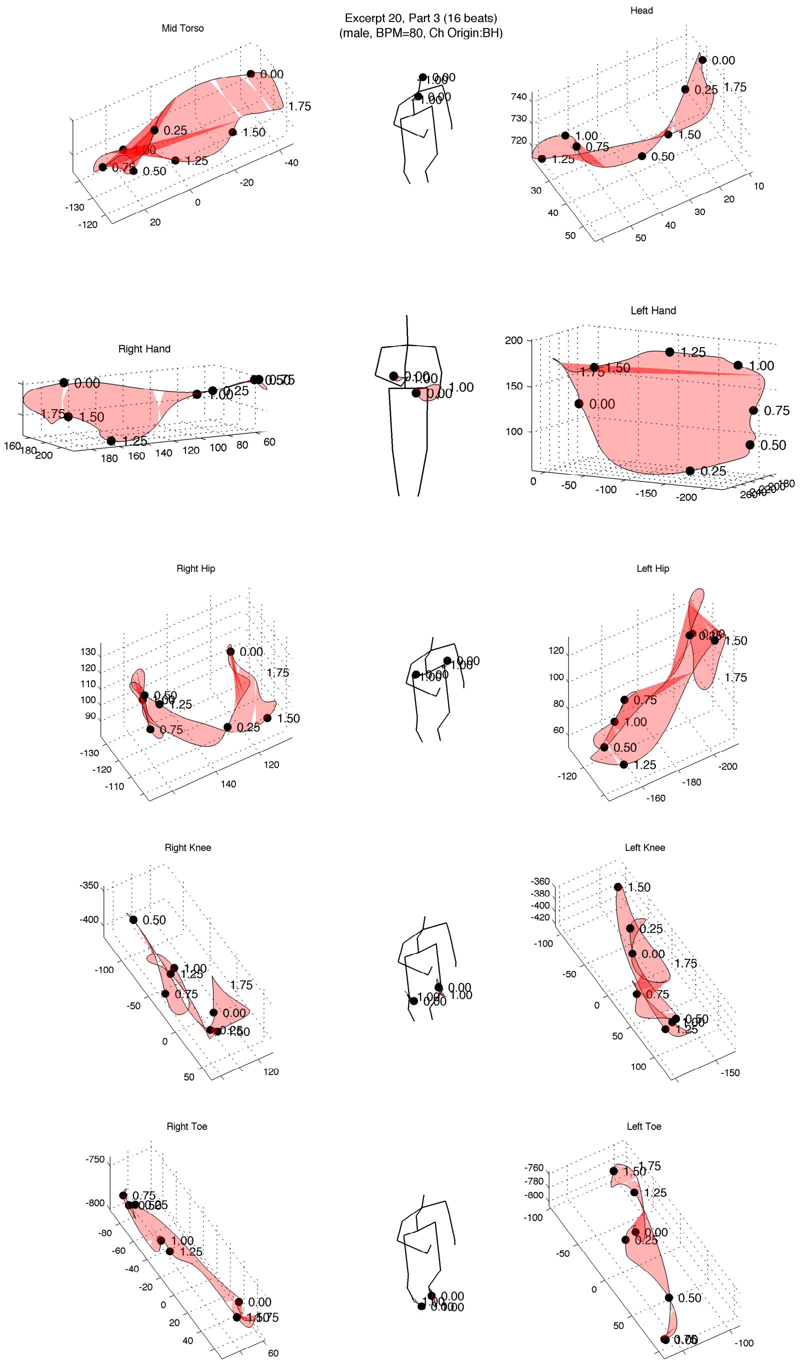


Figure B.40: Detailed view of the basic gestures for excerpt 20, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

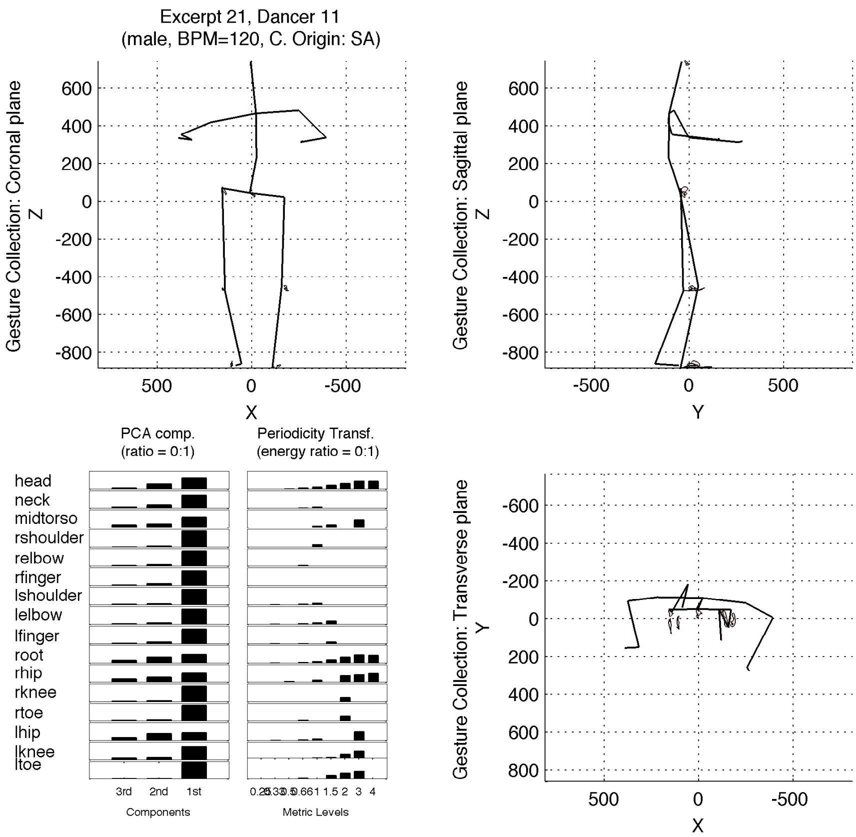


Figure B.41: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 21.

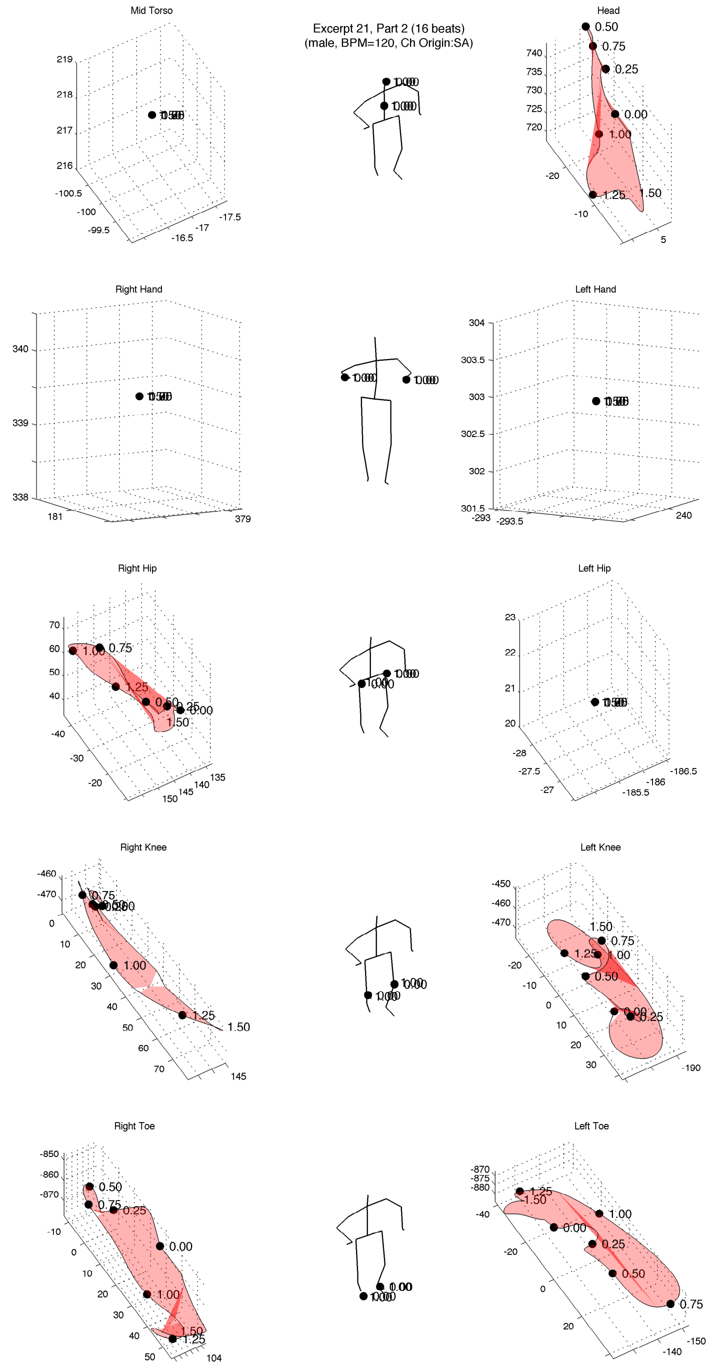


Figure B.42: Detailed view of the basic gestures for excerpt 21, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

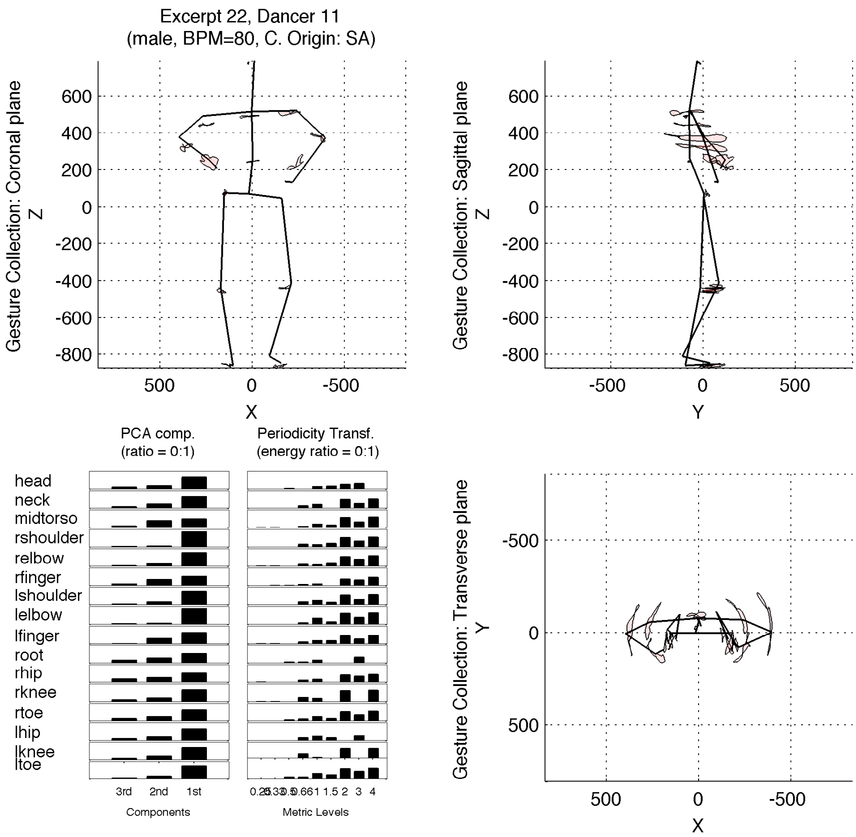


Figure B.43: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 22.

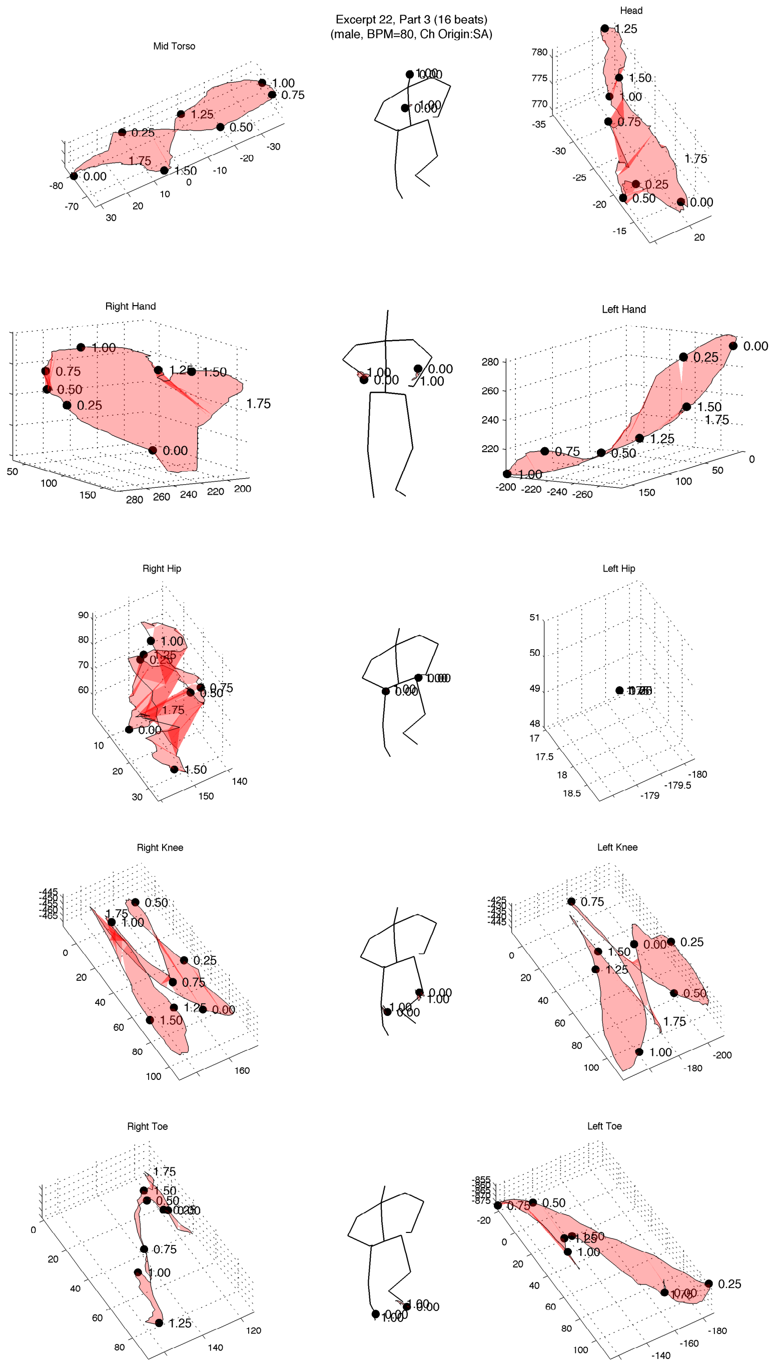


Figure B.44: Detailed view of the basic gestures for excerpt 22, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

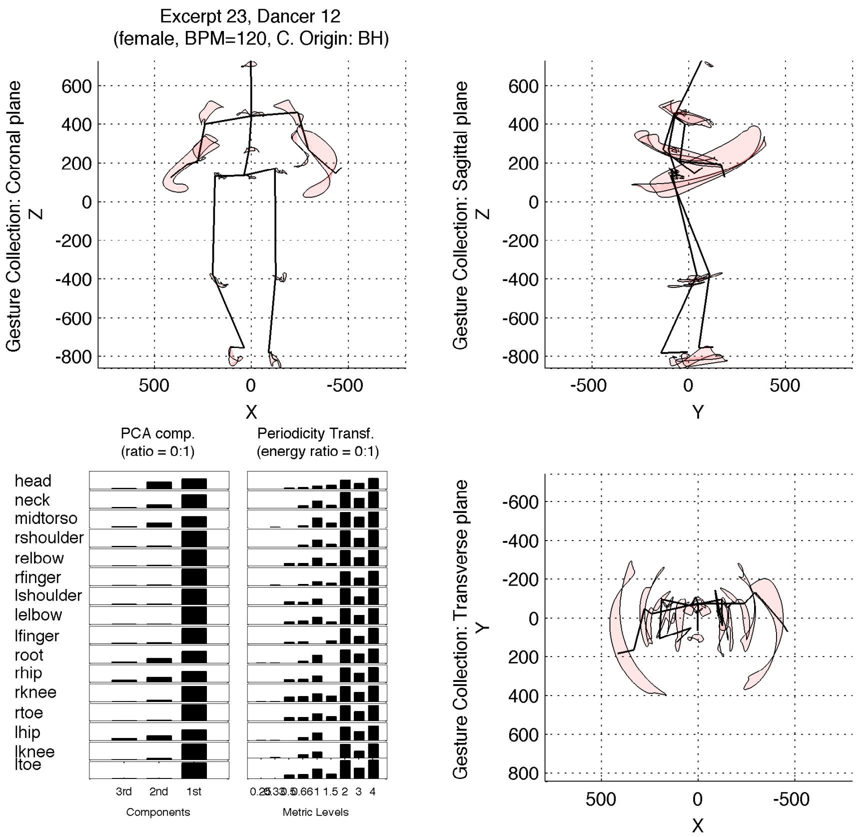


Figure B.45: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 23.

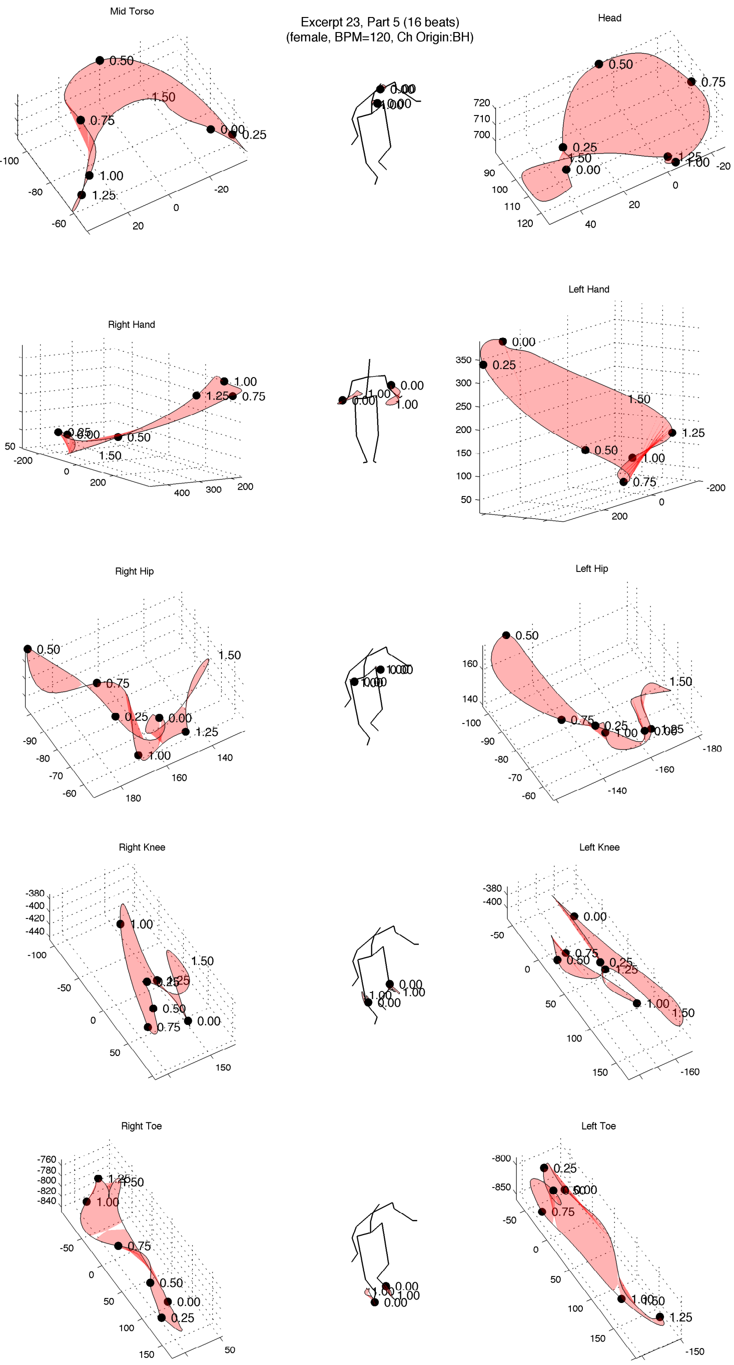


Figure B.46: Detailed view of the basic gestures for excerpt 23, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

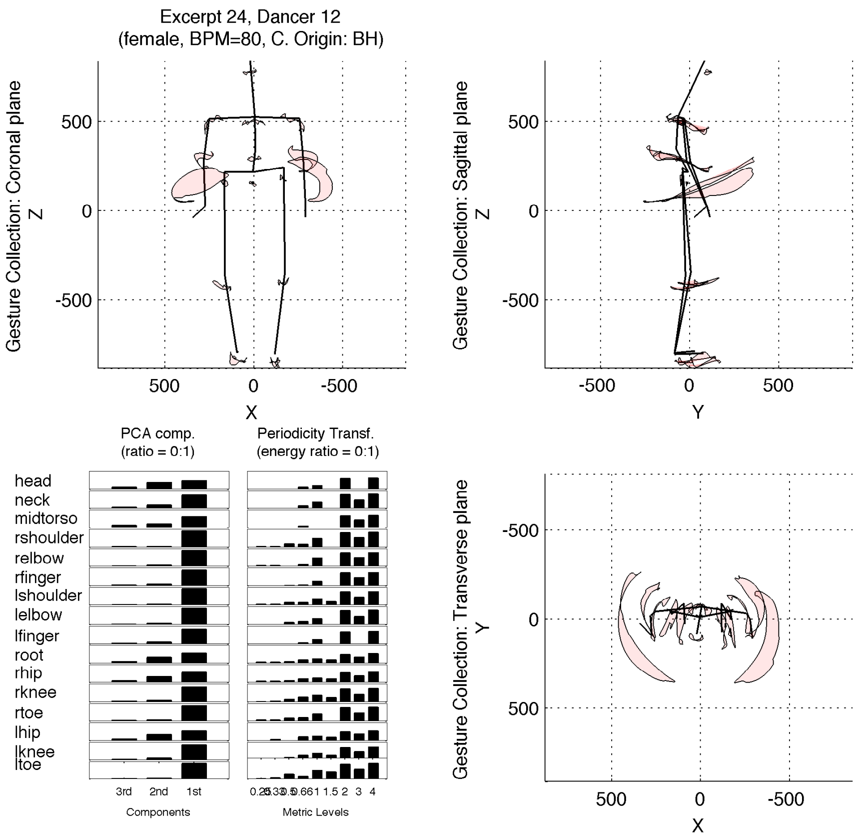


Figure B.47: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 24.

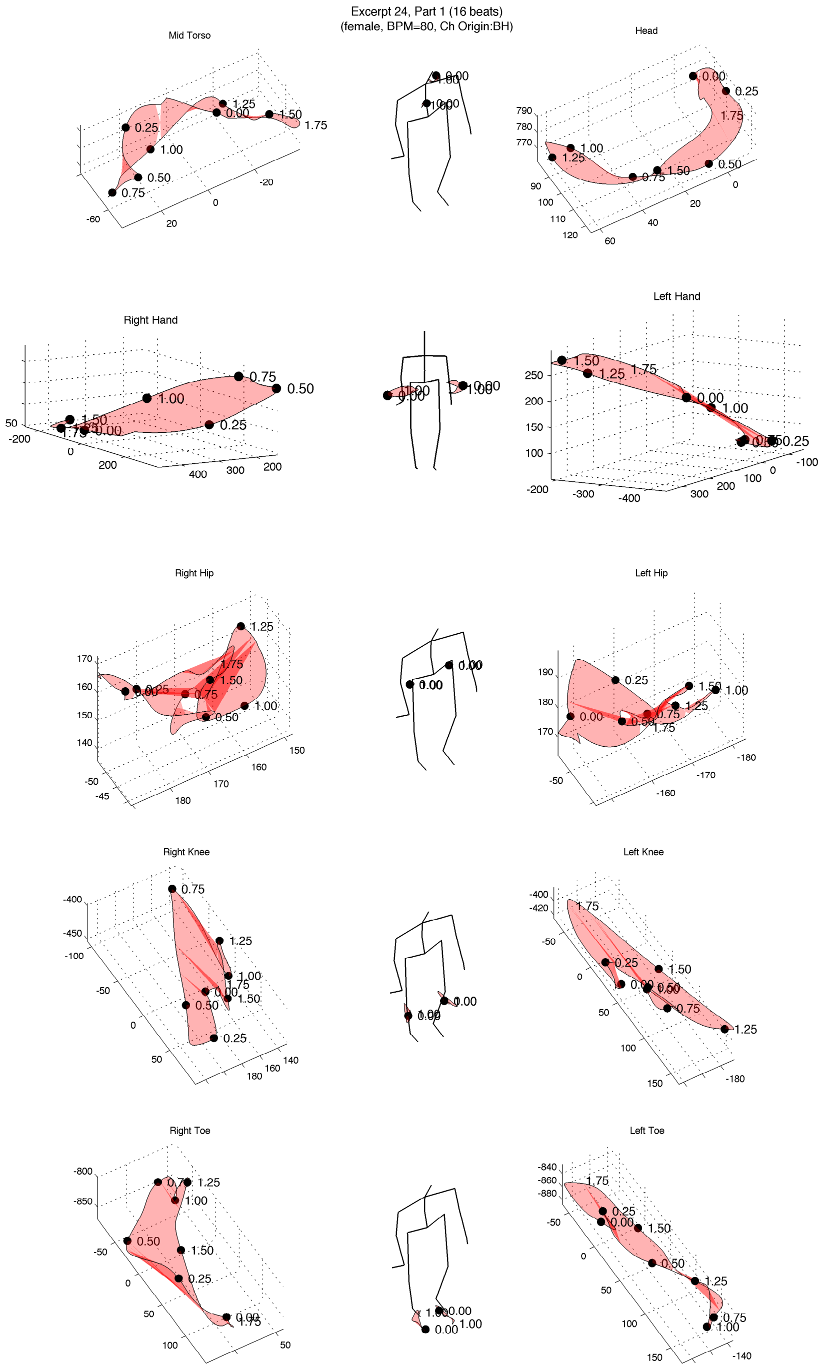


Figure B.48: Detailed view of the basic gestures for excerpt 24, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

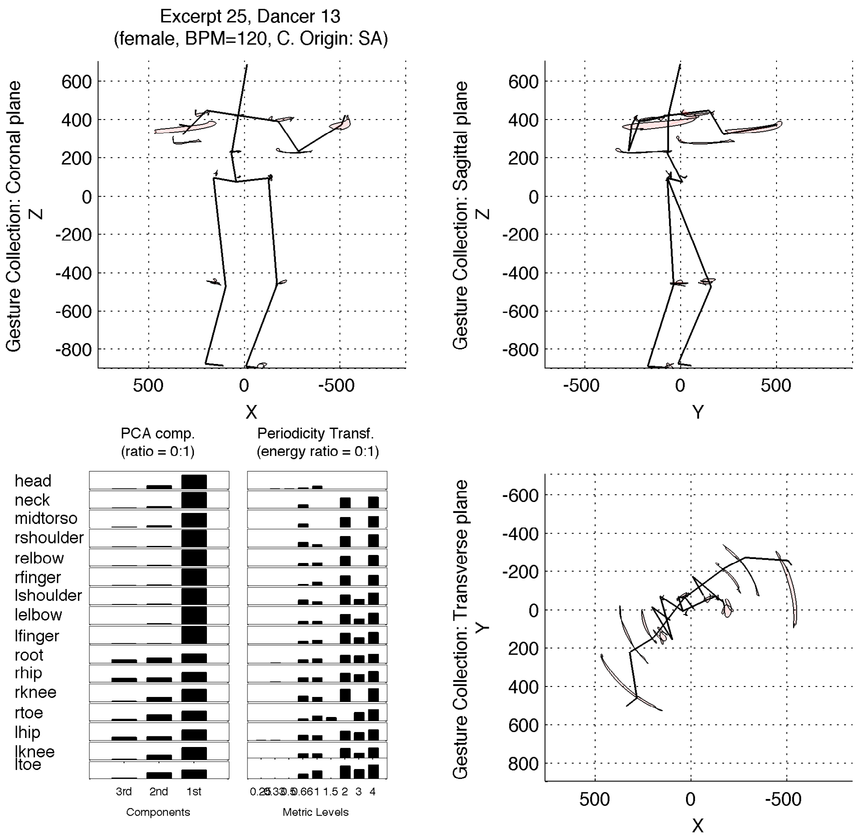


Figure B.49: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 25.

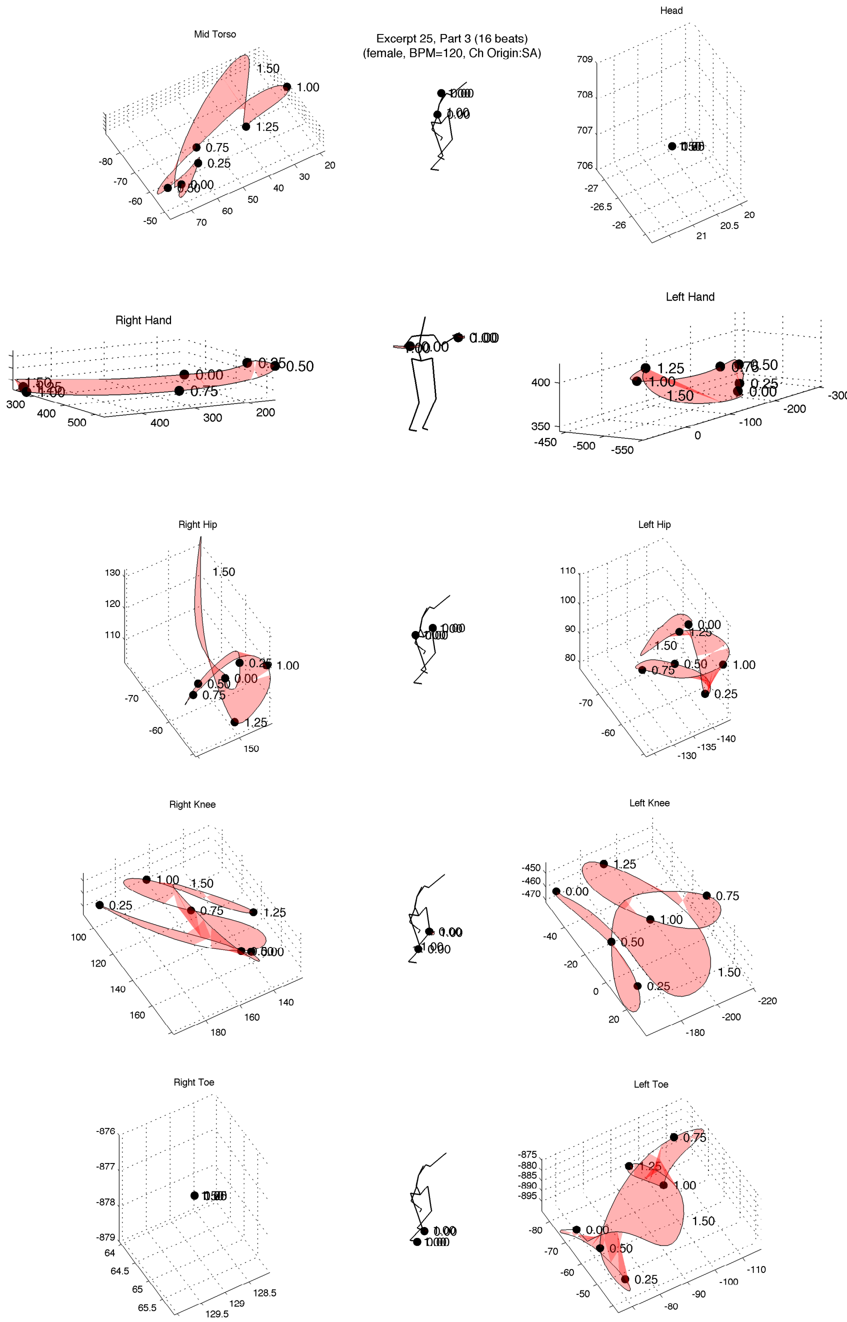


Figure B.50: Detailed view of the basic gestures for excerpt 25, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

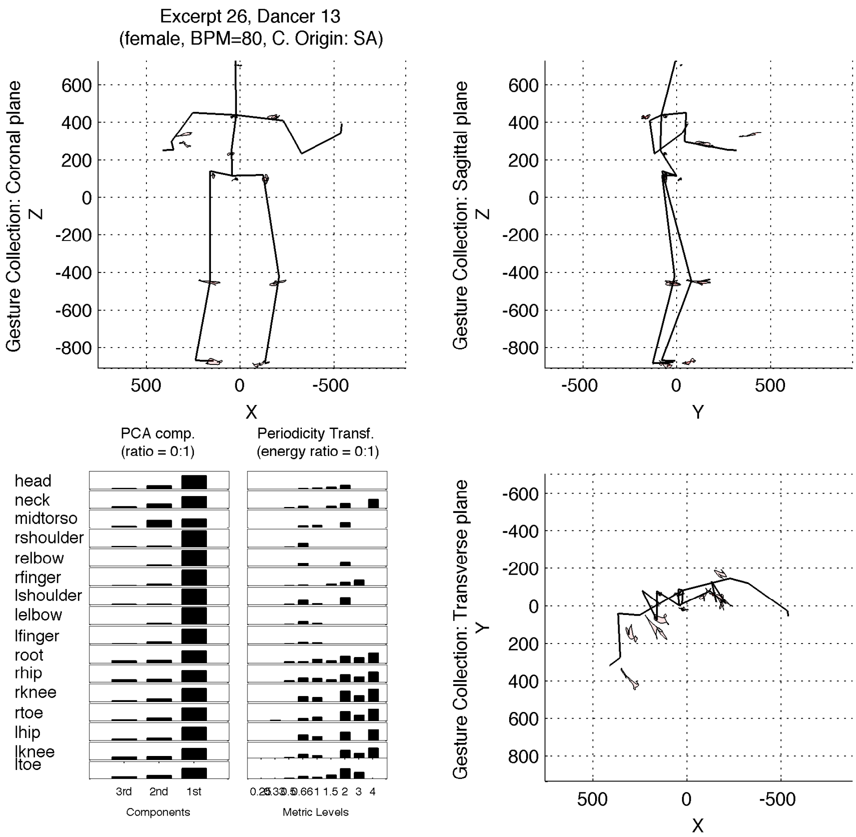


Figure B.51: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 26.

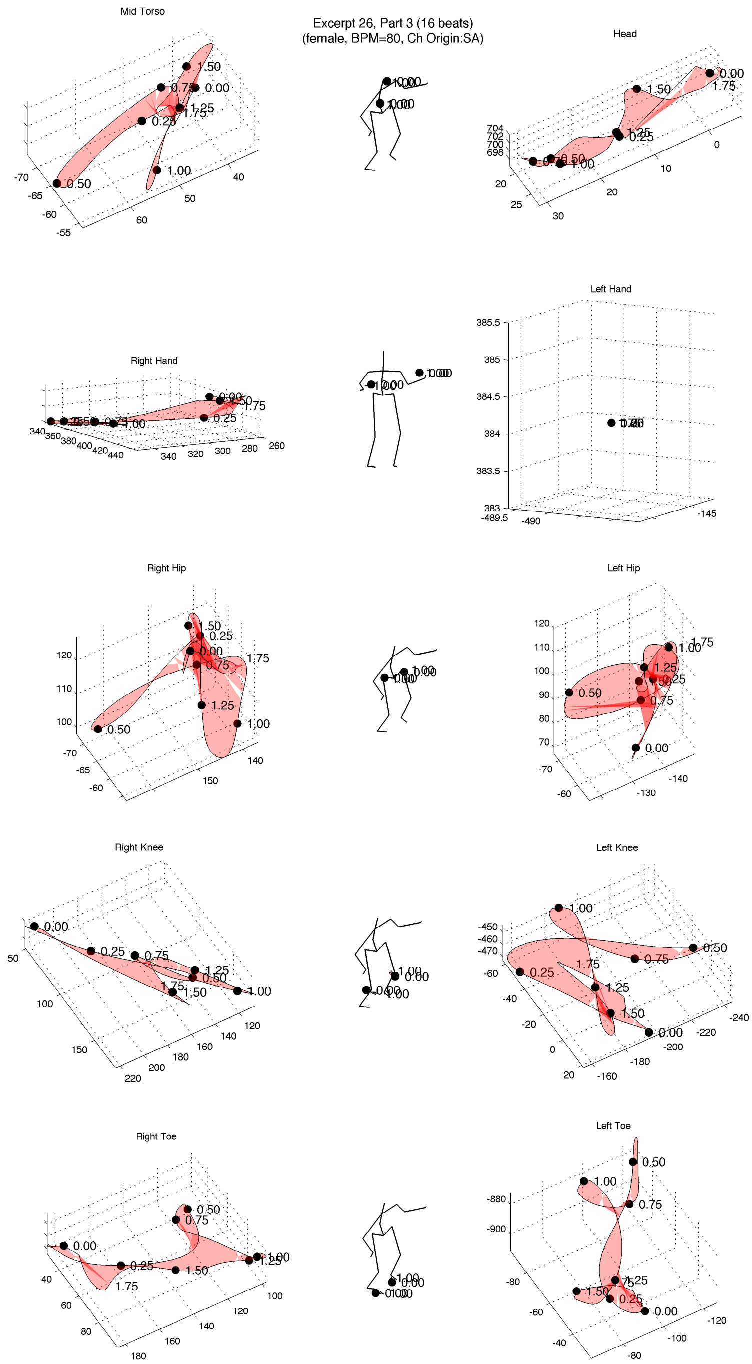


Figure B.52: Detailed view of the basic gestures for excerpt 26, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

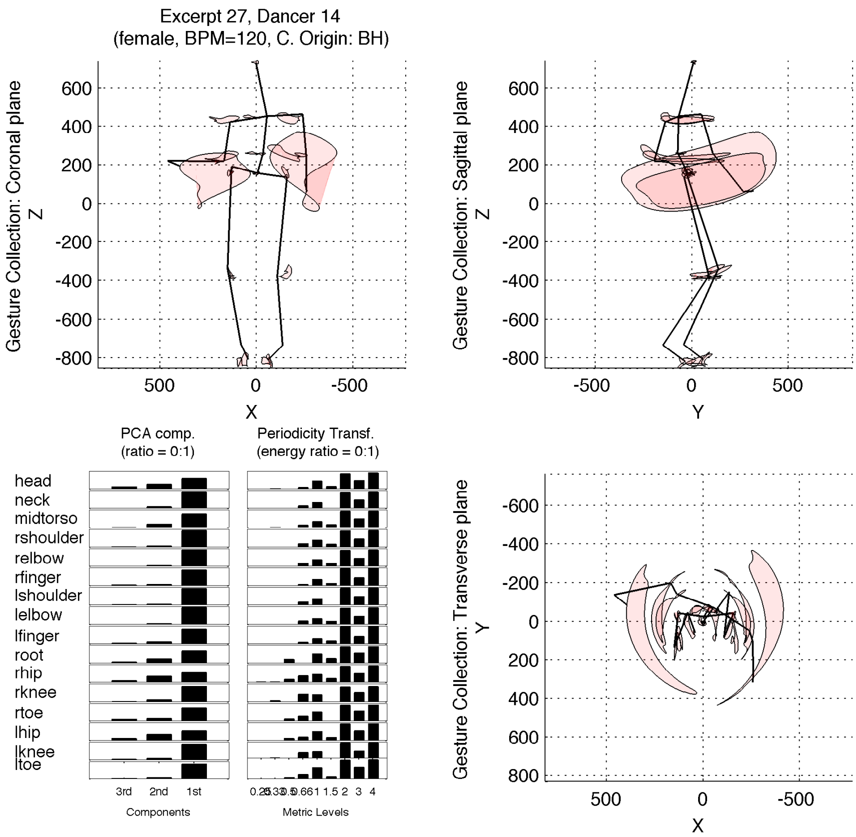


Figure B.53: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 27.

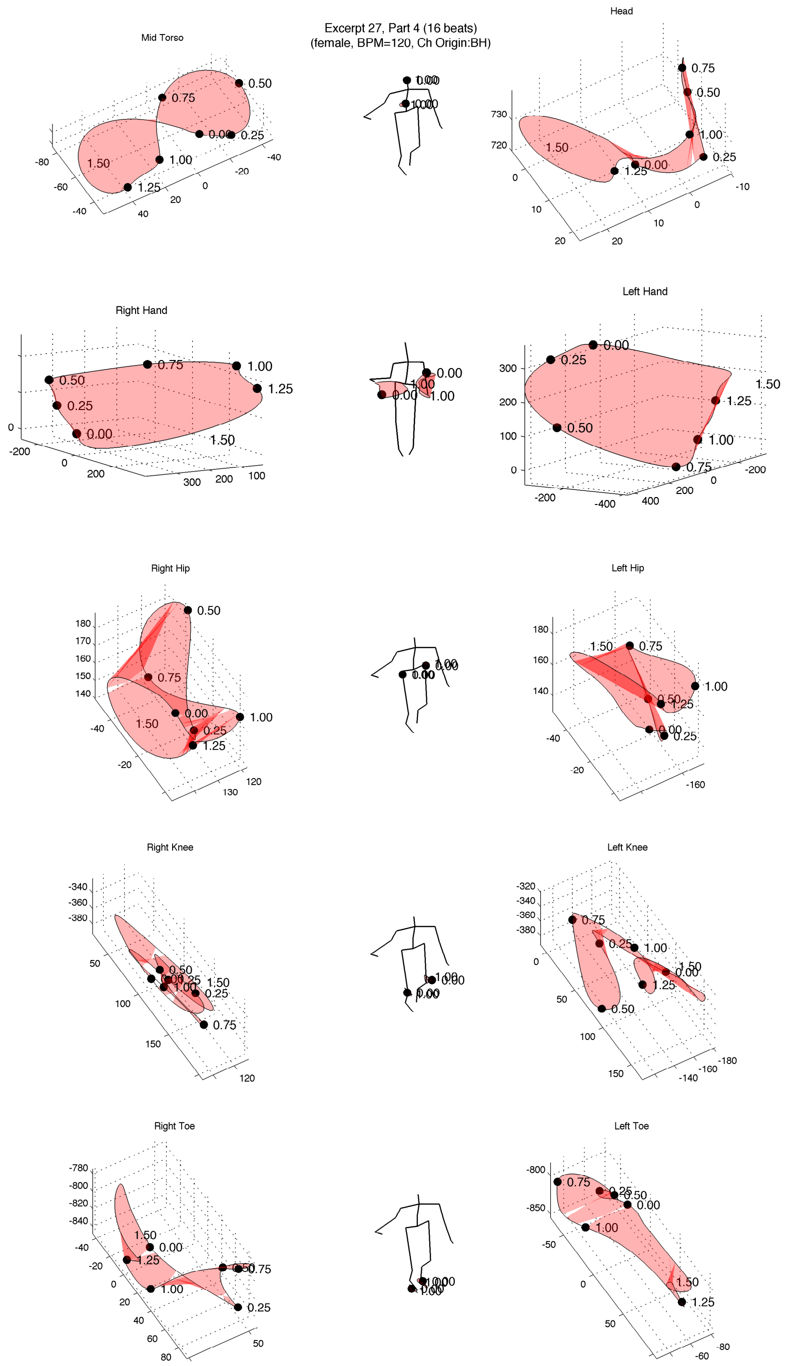


Figure B.54: Detailed view of the basic gestures for excerpt 27, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

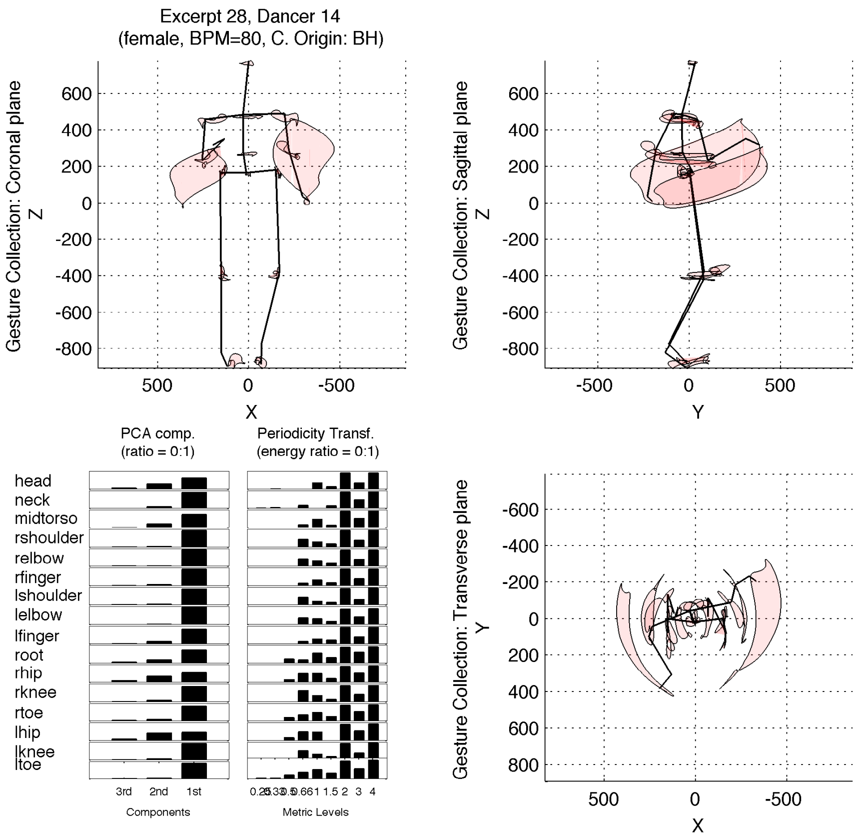


Figure B.55: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 28.

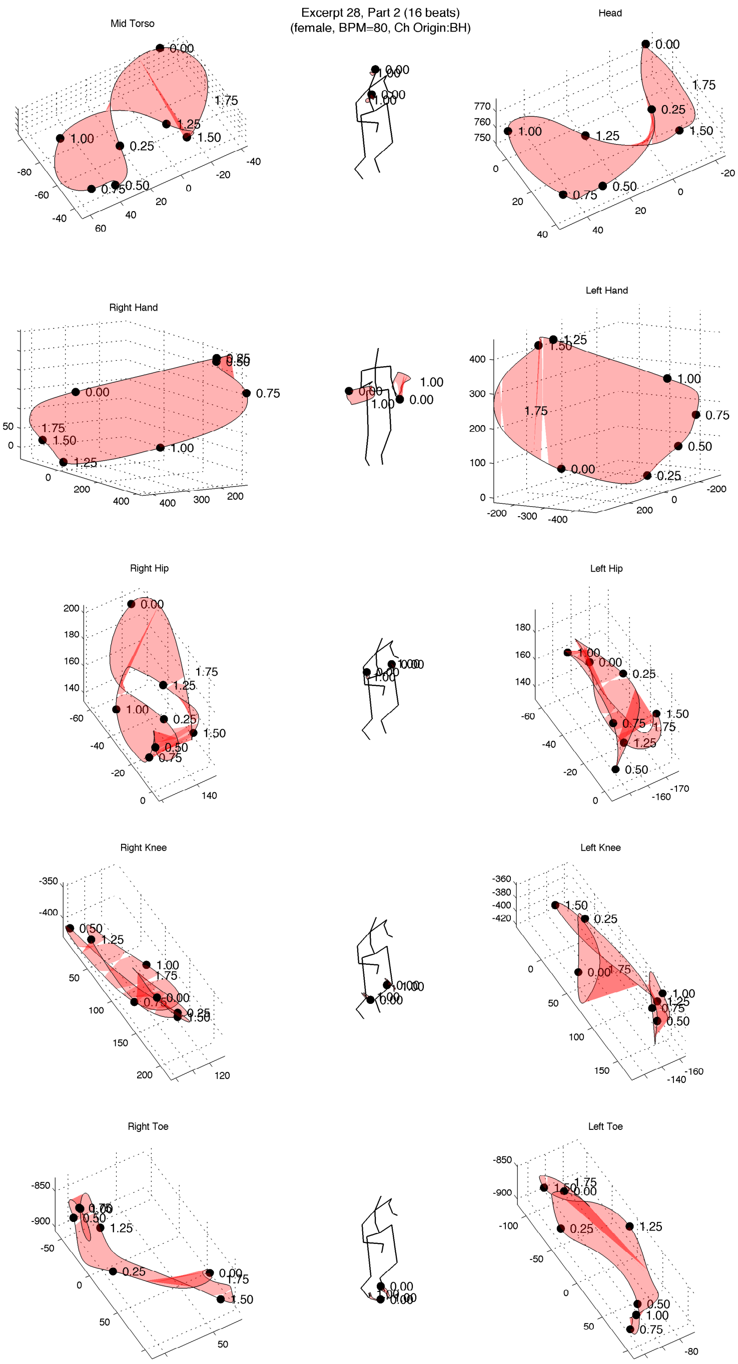


Figure B.56: Detailed view of the basic gestures for excerpt 28, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

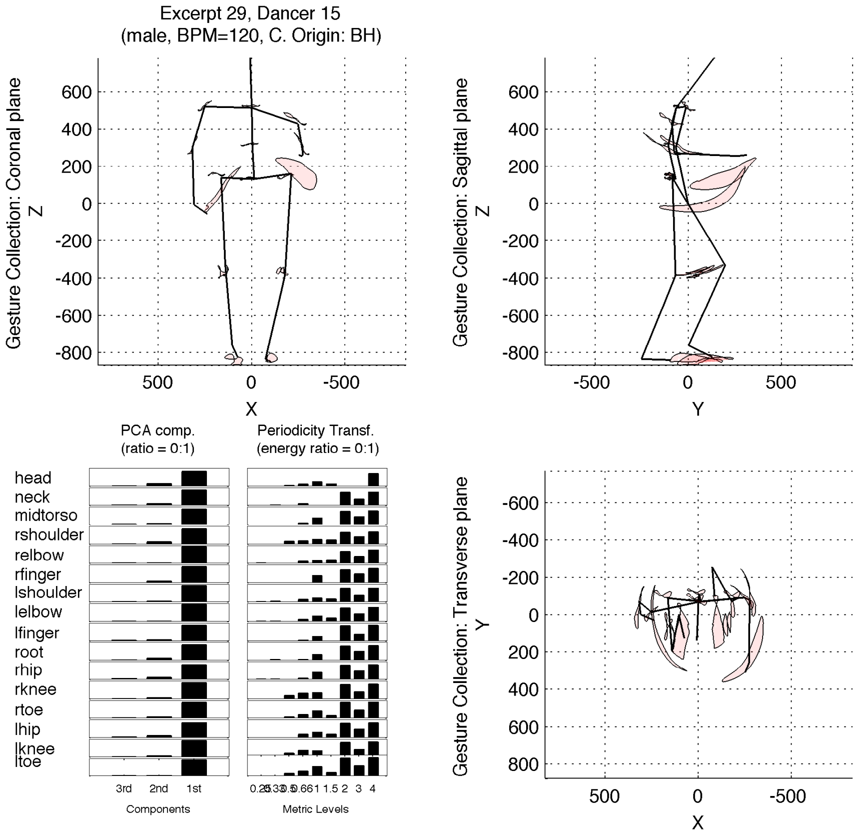


Figure B.57: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 29.

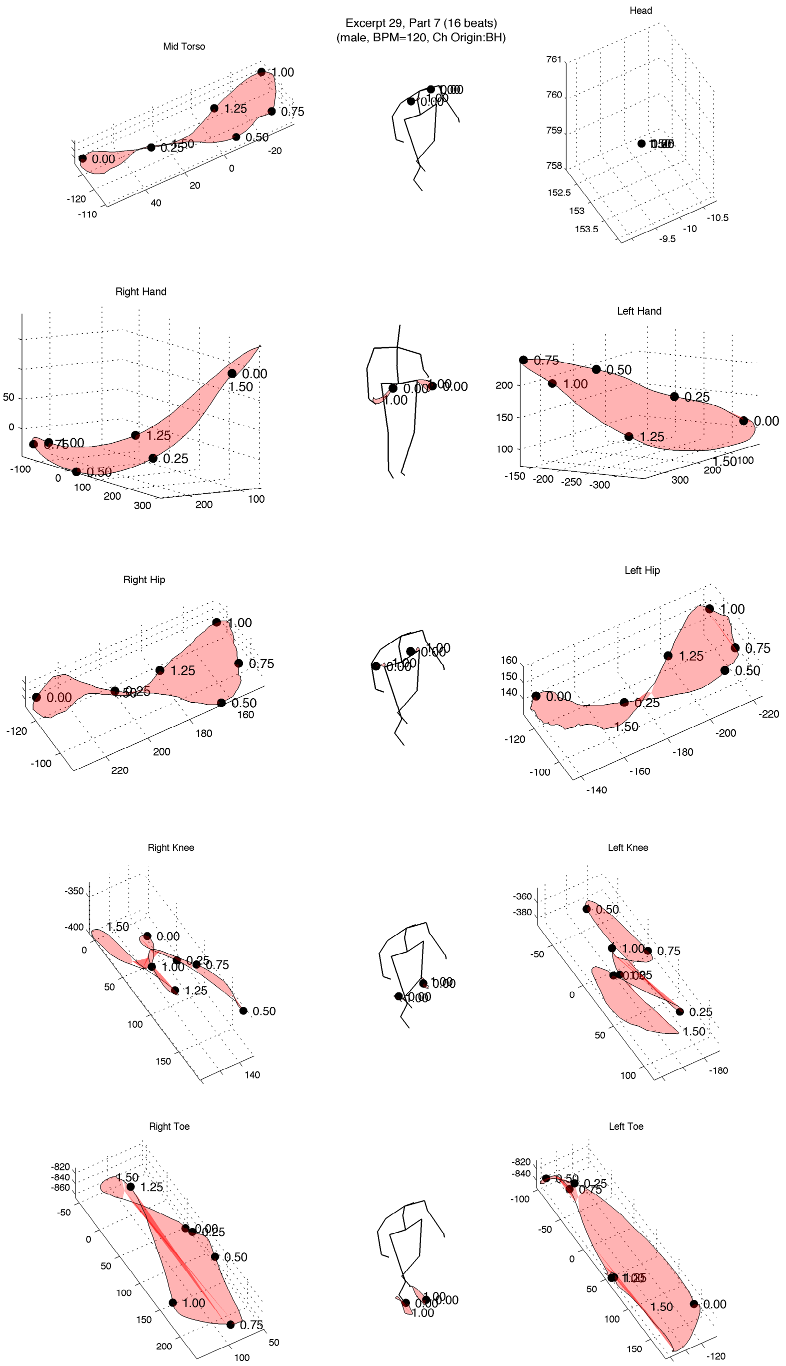


Figure B.58: Detailed view of the basic gestures for excerpt 29, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

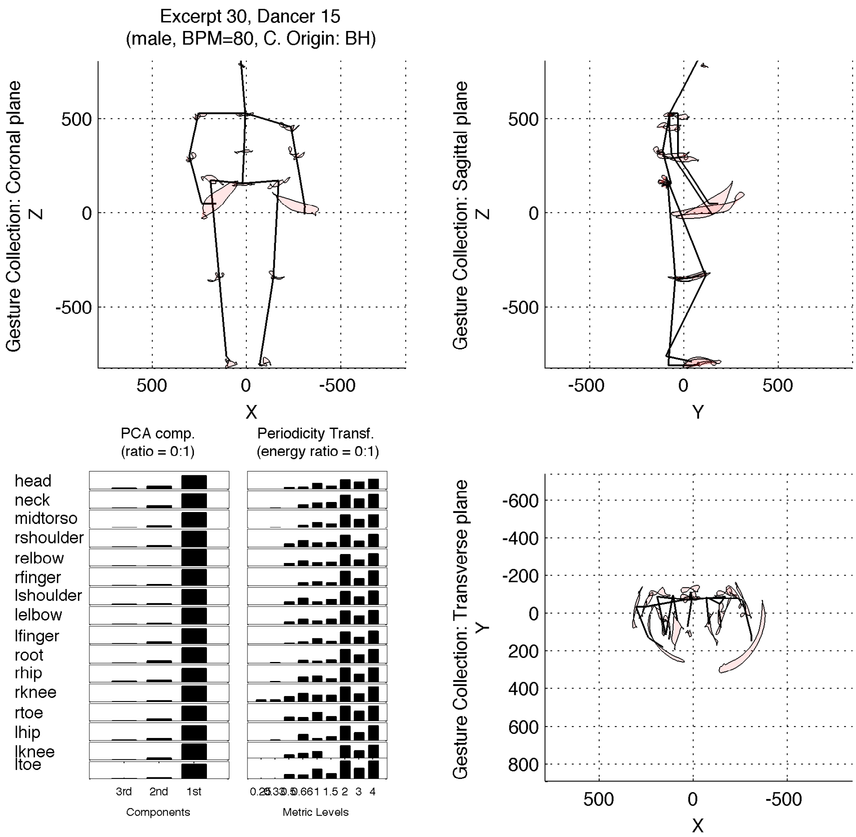


Figure B.59: Overview of basic gestures, variance and periodicities for 16 joints of the excerpt 30.

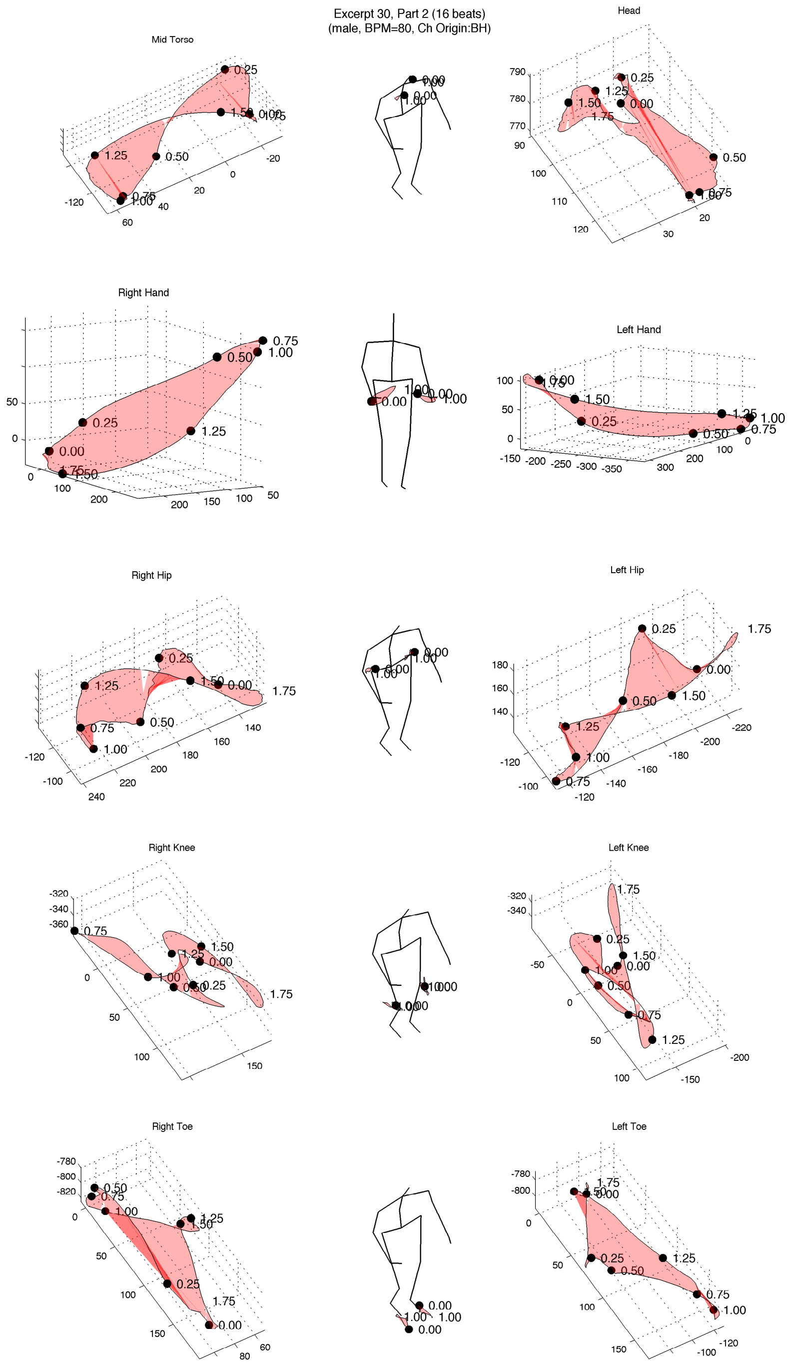


Figure B.60: Detailed view of the basic gestures for excerpt 30, metric level 2-beat. Metric points are projected on each 0.25 beat steps of the basic gesture.

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