Steps towards a Generative Theory of Dance Cognition

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Note: this is exploratory and preliminary work – comments are very welcome.

Abstract

In recent years, the formal methods used in generative linguistics have proved fruitful for the study of music cognition (see esp. Lerdahl & Jackendoff 1983: *Generative Theory of Tonal Music*). At the same time, a wealth of studies has emerged on sign languages, investigating the impact of a different modality (visual vs. auditory) on linguistic systems. These two recent developments taken together raise the following question: is there a gestural counterpart of music, the study of which could shed new light on human cognition?

The hypothesis that this paper investigates, using formal methods, is that there exists a grammar of dance, i.e., cognitive structures underlying the understanding of dance movement, a counterpart of music in the visual modality. Specifically, we ask: what are the primitive elements of dance (cf. phonology)? What are the rules of combination (cf. prosody/morphology/syntax)? What is the meaning of dance if any (cf. semantics)?

The paper is a first attempt to address the first two questions by examining some organizational principles of the mental representation of dance perception. Specifically, the grouping structure of dance is explored in details, based on Gestalt principles and their adaptation to music by Lerdahl and Jackendoff (1983), while other types of hierarchical structures such as metrical structure are briefly discussed.

Ultimately, the goal is to elaborate a theory of dance cognition, which should shed further light on cognitive systems by distinguishing between general cognitive properties and modality-specific or domain-specific properties. In particular, the specific cognitive relation between music and dance should be clarified.

Introduction

In the recent years, some researchers have applied the methodology and the theoretical framework of generative linguistics to questions of music cognition. In a set of lectures given at Harvard in 1973 (published in 1976 as *the Unanswered Question*), Leonard Bernstein first set out to analyze the Western tonal music based on a Chomskian approach of linguistics. This inspired Fred Lerdahl and Ray Jackendoff to write their *Generative Theory of Tonal Music* (1983) where they explore in depth different organizational principles governing the structure of music. Several linguistics and musicologists (Katz & Pesetsky 2011, Rebuschat *et al.* 2011, and references therein, a.o.) have since examined the issue and delved into comparative analyses of the cognitive systems of music and language. Even if the extent of similarity between the two systems is subject to controversy (Jackendoff 2009, Lerdahl 2013 vs. Katz & Pesetsky 2011, a.o.), the adoption of linguistic methodology to music has proved fruitful and the comparison

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between language and music will shed new light on general questions about human cognition.

At the same time, a wealth of studies has recently emerged on sign languages (Emmorey 2001, Sandler & Lillo-Martin 2006, Schlenker 2014, a.o.), investigating the impact of a different modality (visual vs. auditory) on linguistic systems. What they reveal is that despite some modality-based differences, sign languages and spoken languages are by and large part of the same abstract system.

These two recent developments taken together raise the following question: is there a gestural counterpart of music? The comparison between language and music on the one hand, and between sign and spoken languages on the other hand, indeed points to a missing piece in the comparison: just like language can be expressed in different modalities, as a sound-based or sign-based system, can music also be expressed in the spatial modality? Patel (2008) implicitly answers by the negative in assuming that "sign music" does not exist: according to him, there is no

"nonreferential but richly organized system of visual signs with discrete elements and principles of syntax, created and shared for aesthetic ends by an appreciative community" (Patel 2008: 376).

The goal of this paper is to challenge this claim and to hypothesize that dance as a cognitive system is the equivalent of music in the visual modality.

This hypothesis raises several questions to be investigated. Firstly, this supposes that the study of dance cognition, just like that of music cognition, can benefit from the methodology adopted in formal linguistics. To know whether a generative theory of dance is feasible, we need to examine the organizational principles underlying the understanding of dance to potentially determine a 'grammar' of dance. In other words, the issues to be explored are as follows: what are the primitive elements of dance? what are the rules of combination? what is the meaning of dance, if any?

Furthermore, formulating such hypotheses about the fundamental concepts of dance structure should shed new light on the cognitive status of dance perception: to what extent is it learned and to what extent is it due to a innate (unconscious) capacity? To what extent are the principles governing dance perception specific to dance, or shared with other cognitive systems such as music, movement perception, language or even vision? In particular, dance can be compared to music and thereby provide information on the relation between spoken languages and sign languages: assuming that transposition from one modality to another is subject to the same general properties, differences between sign languages and spoken languages should be mirrored by differences between dance and music. Conversely, comparing dance and sign language could be informative for the comparison between music and spoken languages: examining the relation between music and language in two different modalities should reveal more general and abstract properties about the two systems and make their comparison easier. In sum, the examination of the missing piece, i.e. dance, in the comparison between music and language, should shed new light on all these cognitive systems by distinguishing between modality-specific or domain-specific properties and general cognitive properties, and thereby help us make progress in the understanding of human cognition. To what extent are the four cognitive systems indicated in Table 1 modular, to what extent is there cognitive overlap?

Modality\Domain	*Referential (languages)*	*Non referential (art)*
Sound	Spoken languages	Music
Space	Sign languages	**Dance**

Table 1. Dance: the missing piece in the comparison between languages and music

The present article takes some steps towards this general goal by mainly focusing on the study of grouping structure in dance based on the theory of grouping structure in music by Lerdahl and Jackendoff (1983). After further specifying the object of study in Section 1, I will set the stage for transposing musical grouping principles to dance in Section 2. Section 3 is devoted to a precise examination of the grouping structure of dance. Finally, in Section 4, I will briefly discuss other types of hierarchical structures in dance based on a comparison with pitch structure and metrical structure in music, which will lead me to address the issue of the structural properties of a dance-music event.

1. The object of study: the underlying structure of dance as set of movements

1.1. The structural, unartistic aspect of dance

It should be clear that it is not the artistic aspect of dance that will be of interest here, but the 'grammar' that underlies it. Just like the artistic structure and effects of a poem cannot be appreciated unless the grammar of the language used in the poem is understood, I hypothesize that in order to appreciate a choreography as art, we must first understand the basic and obvious aspects of dance organization. In short, our object of study is what is taken for granted in dance theory, that is, the basic structural rules that govern the organization of dance movement.

By dance, I refer to a sequence of movements, which can in principle be distinguished from its artistic effects, and does not have any other goal than movement itself. In linguistic theory, we are interested in everyday sentences, to uncover the unconscious rules that govern their structure; we do not study literary and poetic sentences because they are more complex in being also subject to intentional rules related to art creation; these more complex, ambiguous and controversial aspects are studied by theories about literature and style. Similarly here, we would ideally want to study 'everyday dance' to disentangle the artistic from the grammatical aspects of movement. But as Lerdahl and Jackendoff (1983) mention for music, there does not seem to be an equivalent of everyday sentences in the domain of dance: everyday movements are usually goal-oriented, which makes them fundamentally different from dance.[2] This absence of everyday music or dance as opposed to everyday language may be due to the intrinsic

[2] It is nevertheless plausible that dance shares some of its structural characteristics with other kinds of human movement, or even with motion in general. Accordingly, different dance principles could be distinguished depending on their specificity. Asking this kind of questions could help us determine to which extent dance perception is linked to a specific cognitive module or shares its properties with other cognitive systems.

difference between music/dance and language with respect to referentiality: the latter aims at delivering a message in relation to the external world, the former does not have any other goal than itself. Note for that matter that I exclude from this study figurative dance (the extreme form of which is pantomime) whose function is to represent (mime) a story or a situation, or to convey a specific message that could be translated into words.
Only abstract dance is of interest here, or more specifically its substrate of basic organization that defines the terms in which artistic options can be stated. Since there is no dance counterpart of everyday sentences,[3] we will concentrate on the parameters responsible for obvious intuitions about dance movement, which are then manipulated to create artistically interesting phenomena. In short, we are interested in the apparently uninteresting aspects of dance that have been overlooked because they seem obvious. But in fact, the hypothesis here is that these fundamental concepts of dance structure are precisely interesting because they are obvious: they can shed light on our unconscious mental representations, i.e. on a potential human capacity for dance.

1.2. The universal properties of dance

This means that no specific dance idiom is of interest here, but the general properties common to all dance styles, irrespective of the cultural norms they obey. It could be objected that such a hypothesis relies on ethnocentrism: Lerdahl and Jackendoff's (1983) study of Western tonal music as a way to understand the general structure of music has encountered this kind of skepticism. Similarly, it is sometimes argued that linguistic theories are biased by their mainly focusing on English. But even if it is true that a given language may allow us to uncover some general properties of language more easily than others and thus temporarily bias the general conception of linguistic theory, it does not hold that it is impossible to find general properties of language based on the study of a particular language and its comparison with others. The hypothesis here is that any kind of dance, whether it is ballet, hip hop, tango, Indian dance or any other kind of dance from any place or time, and whether it is an individual dance, a dance in couple or in groups, will produce the same kind of cognitive effects on the observer,[4] in the sense that spectators will construct the same kind of structured mental representations when perceiving a set of dance movements (whether it is called dance or not, in fact). This does not mean that the same emotions will be triggered, or that a given dance will be understood as a sequence of movements structured in the same exact way by all

[3] 'Everyday sentences' in the sense intended here also include sentences in sign languages, which are obviously part of the linguistic system: sign language is the spatial counterpart of spoken language, not of language in general.
[4] The existence of several systems of dance notation depending on the dance type, and the difficulty of translating a given choreography into another system of notation, are not arguments against the existence of universals in dance either: it may be similarly difficult to use some alphabets to write some languages, just because the relevant aspects of a given language cannot necessarily be noted in all alphabets. It is not because all general properties of language are not visible in any given language that such general properties do not exist. The same holds for dance: it is not because all relevant aspects of movement are not exploited in the same way by all dance styles that there is no universal aspect of movement.

observers, but that there are universal, unconscious cognitive rules[5] that constrain the way a given dance can be perceived by a human being.[6]

1.3. The perception of dance

It is indeed the perspective of perception, not that of production or performance, that is adopted here. There is a fundamental difference between language and music/dance in this respect: while under normal conditions, any human being can speak and understand a language without specific training (his/her native language), it does not seem to be the case that any human being can produce or perform a piece of music or dance, especially not without training: some individuals are more competent than others, and learn more quickly than others. However, any human being is able to perceive a piece of music or a choreography as a mentally constructed entity. Of course, the richness of the representations may vary depending on the observers' exposure to dance or music and their potential training in specific idioms of these arts. But similarly, not all native English speakers understand a poem by Shakespeare in the same way, depending on their familiarity and competence in poetry and Shakespearean work, but as native speakers of English, they are all able to construct a mental representation of it. The same holds for dance: even someone who has never heard of rhumba before will perceive a rhumba dance as a mentally produced organization, not as an unanalyzed physical signal: because of the hypothesized cognitive faculties at use when perceiving dance, the way a given dance can be perceived can be predicted to some extent. Note that I here talk about cognitive, psychological aspects of perception, not physical ones: it has recently been noticed that watching another body moving has a physical, sensorial impact on the observer (Hagendoorn 2004, Foster 2008, a.o.; cf. studies of the mirror neuron, Berthoz 2001, a.o.); this is not what is of interest here, nor are the real-time processes involved in watching dance. What I am after is the form of the final state of the psychological understanding of a sequence of movements, that is, the mental products inferred from a physical signal consisting of dance movement.

[5] As mentioned by Patel (2008: 356), the universality of a human competency does not necessarily entail its biological foundation: although it is universal in human cultures, the mastery of fire is not part of human biology, but is a cultural invention; according to him, the same holds for the musical ability. Other diagnostics than universality are thus necessary to distinguish between cultural invention and biology. Bailyn (2015) uses Fodor's (1973) diagnostics, i.e. automaticity and rapidity, informational encapsulation, domain specificity, neural specificity and innateness to argue (against Patel) that musical perception comprises a cognitive module. Such diagnostics should ultimately be used in the case of dance too to decide on the status of the cognitive system of dance. In fact, Bailyn (2015: 37-38) suggests that dance could correspond to music expressed in the visual modality, which would imply that the same diagnostics should yield the same result for dance.

[6] To account for the differences between dance idioms, we will moreover need a theory of dance variation, in the same way as we need to account for variation in music and language (cf. theory of Principles and Parameters, Chomsky 1981).

1.4. Independence from music

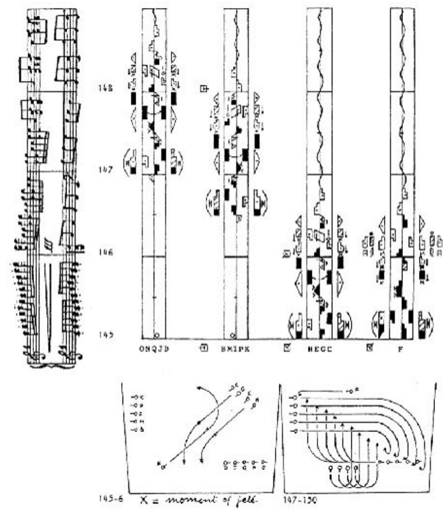

Figure 1. Laban's example of labanotation
(from https://www.pinterest.com/)

Finally, dance will be examined as a cognitive system on its own, independently of music. The issue of the independence of dance with respect to music arises because dance has been traditionally defined in function of music: under this definition, dance intrinsically depends on music and does not exist without music; it is the visualization of music. But here, I assume that dance and music are independent, as now widely accepted in the dance community and elsewhere: Laban's efforts to create a new system of dance notation different from music notation are emblematic of this (see Figure 1). Even if it is much more common to listen to music unaccompanied of dance than to watch a dance performance unaccompanied with music, dance in silence does exist, especially in contemporary choreographies (by Yvonne Rainer, Lucinda Childs, Trisha Brown, a.o.); the fact that deaf people do dance, perform and compose choreographies (e.g. National Deaf Dance Theater) supports this idea too. Furthermore, even if many choreographers create their sequences of movement based on the music (e.g. George Balanchine), others do the opposite: Merce Cunningham, who denies any rapport between music and dance in either structure or mood, randomly assigns music to his choreographies and even brings together music and dance for the first time in the final dress rehearsal before a performance, which makes music a mere background for the choreography; moreover, a choreographer such as Jean-Claude Gallotta has adapted the same choreography, *Ulysse*, to several pieces of music (*Ulysse* 1981, *Ulysse, re-création* 1993, *Les Variations d'Ulysse* 1995 and *Cher Ulysse* 2007), which also demonstrates the independence of dance and music.

We need to note, nevertheless, that methods such as Cunningham's or Gallotta's are perceived as unusual, deviant from the norm, which implies that the norm is that dance is associated with music. This norm, moreover, does not seem to be culturally determined as most dance styles across the world and across history are associated with music: traditional examples of dance/music couplings include Baroque, jig, waltz, tango, disco, salsa…. This does not necessarily mean, however, that dance depends on music: several types of music are conversely composed specifically to facilitate or accompany dancing, especially ballroom dancing, and some dances (e.g. tap dance) may even provide their own accompaniment in place of music. But this means that the association between dance and music is natural, and may suggest that dance and music share some cognitive properties or are even part of the same cognitive module.

Methodologically, this implies that both an investigation of dance independently of music and an examination of the correspondence between dance and music happening simultaneously are necessary. The former issue is mainly addressed in this paper, while the latter is briefly discussed in Section 4.

Thus, the goal of the project is in short to attain a formal description of the dance intuitions of a spectator, that is, an analysis of the principles underlying the mental representations of a sequence of dance movements: how is dance organized in terms of theoretical constructs? what are the unconscious and universal rules that model the observer's connection between the presented dance performance and the structure (s)he assigns to the performance? Ultimately, the aim is to develop a theory of the dance cognitive capacity by teasing apart the universal principles of dance grammar from the artistically relevant aspects of dance.

In this paper, we take steps in this direction by hypothesizing and exploring some basic parameters and rules of dance structure based on the principles of grouping structure that Lerdahl and Jackendoff (1983) have assumed for music.

2. How to transpose grouping structure to dance

2.1. Grouping structure in music (Lerdahl & Jackendoff 1983)

Lerdahl and Jackendoff (1983) are interested in the components of musical intuition that are hierarchical in nature, and propose four such components:

"(i) *grouping structure* expresses a hierarchical segmentation of the piece into motives, phrases and sections;
(ii) *metrical structure* expresses the intuition that the events of the piece are related to a regular alternation of strong and weak beats at a number of hierarchical levels;
(iii) *time-span reduction* assigns to the pitches of the piece a hierarchy of structural important with respect to their position in grouping and metrical structure;
(iv) *prolongational reduction* assigns to the pitches a hierarchy that expresses harmonic and melodic tension-relaxation, continuity and progression."

(Lerdahl & Jackendoff 1983: 8-9)

In other words, musical structure is built out of the confluence of two independent hierarchical dimensions of organization: *rhythm* (i-ii), whose organization is the product of two independent hierarchical structures, namely *grouping* and *meter*; and *pitch* (iii-iv). Each of these components has its own characteristic units and combinatorial principles. The basic unit of grouping is a *group* of one or more adjacent notes in the musical surface; adjacent groups can be combined into larger groups. The basic unit of metrical structure is a *beat*, a point in time usually associated with the onset of a note in the musical surface; beats are combined into a metrical grid, a hierarchical pattern of beats of different relative strengths. The basic unit of pitch structure is a *note* belonging to a tonal pitch space characteristic of the musical idiom; the concatenated notes of a melody are combined hierarchically to form a pattern of tension and relaxation called a reduction.

Grouping, as segmentation of the musical surface into motives, phrases, and sections, can thus be considered as the most basic component of musical understanding. The process of grouping is common to many areas of human cognition: the Gestalt principles illustrate this in the domain of static visual perception. Similarly, Lerdahl and Jackendoff (1983)

assume that the unconscious principles for constructing grouping are pertinent in music: the listener of a piece of music uses them to segment the raw sequences of notes that (s)he hears into hierarchical groups.
According to them, the grouping component consists of two sets of rule: *well-formedness rules* and *preference rules*. The former state the conditions that all possible grouping structures must satisfy, that is, a strict, nonoverlapping, recursive hierarchy, where only contiguous sequences can constitute groups. The latter establish which of the formally possible structures that can be assigned to a piece correspond to the listener's actual intuitions.
Specifically, grouping preference rules are of two types: local detail rules, which lead to perception of group boundaries, and more global rules that determine the organization of larger-level grouping. Several of these rules are based on the Gestalt's perceptual principles by visual analogy: for instance, proximity (with respect to intervals of time) and similarity (with respect to register, dynamics, articulation and length) determine group boundaries, while symmetry and parallelism determine higher level grouping.

The reader is invited to consult Lerdahl and Jackendoff's (1983) book for all the details, but as an illustration, here are the metrical and grouping structures of the beginning of *Norwegian Wood* by the Beatles according to their principles (from Jackendoff and Lerdahl 2006). In Figure 2, each vertical column of x's above the notes represents a beat, and the height of the column indicates the relative strength of the beat; below the notes, the horizontal brackets represent the different groups. In Figure 3, the tree represents the hierarchical structure of pitches based on notions of stability, tension and relaxation.

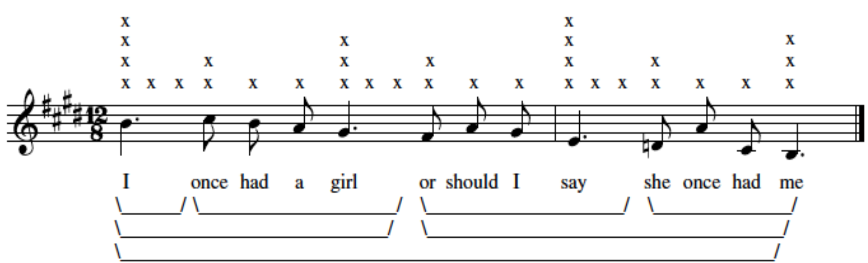

Figure 2. Metrical and grouping structures of the beginning of Norwegian Wood (Jackendoff and Lerdahl 2006: 41)

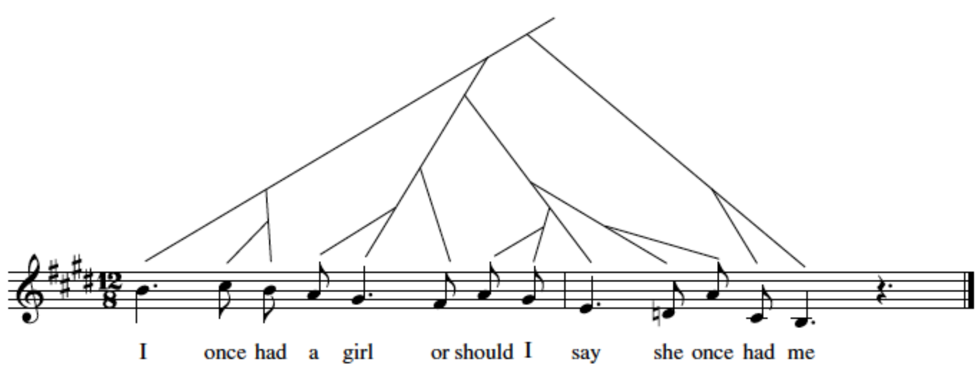

Figure 3. Pitch structure of the beginning of Norwegian Wood (Jackendoff and Lerdahl 2006: 56)

While music basically consists of sound in time, dance is movement unfolding in time. Both types of physical signals thus share the time component, but while the former involves sound perceived by our auditory system, the latter happens in space perceived by our visual system. Furthermore, while music is created by one or several instrument(s) or human voice(s), dance is necessarily created by one or several human bodies. How do these basic physical differences in production correlate with differences in cognitive representations?

2.2. Transposition into dance

Here, I choose to start building a grammar of dance by transposing musical grouping structure into dance. This choice results from several considerations.

First, as explained by Lerdahl and Jackendoff (1983), grouping structure is the most basic component of music understanding; it is thus natural to suppose that it is also the most basic component of dance understanding, which we should start with.

Second, as suggested by Gestalt psychology, grouping structure (as opposed to metrical structure for instance) is extremely broad in its application, which means that it is highly plausible that this component is relevant in dance too, and that inquiring into it will therefore be more informative in the exploration of common properties of cognitive systems.

Third, as opposed to pitch structure, grouping structure is clearly idiom independent: the same rules of grouping hold for any type of music, while this is not obvious for pitch structure: in fact, Lerdahl and Jackendoff's (1983) rules of pitch structure primarily concern Western tonal music. It is thus more likely to find universal organizational principles of dance by investigating grouping structure rather than the gestural counterpart of pitch structure.

Finally, because the parameters for grouping are clearly different in the visual modality than in the auditory modality as we will see, the examination of grouping structure will make it easier to study dance independently of music, which is crucial if we want to compare dance and music as potentially different cognitive systems.

2.3. Building blocks: dance features

To examine the grouping structure of dance, we first need to know what are the primitive elements of dance. Many dances are built out of a finite vocabulary of movements (e.g. the *assemblé* in ballet).[7] But just as there are more primitive units than words or morphemes in spoken languages and signs in sign languages, more abstract units with no meaning in isolation should be found: what are the minimal features of dance, i.e. the equivalents of phonemes in language? Both sign language phonology and dance notation should be informative in this respect.

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[7] Kaeppler (1972: 174) calls *kinemes* the units in dance that are comparable to phonemes, that is, "elements selected from all possible human movements and positions and are recognized as significant by people of a given dance tradition", and builds a grammar for Tongan dance based on this notion. In fact, her kinemes seem to be more similar to *morphemes*, i.e. minimal units of signification, which correspond to signs in sign languages. What we are after in this section are the equivalents of *phonemes*, which correspond to features of signs.

Before the 1960s, signs had been regarded as unanalyzable, unitary gestures. But based on the study of American Sign Language, Stokoe (1960) showed that signs can be considered as compositional with subelements contrasting with each other. Sign language research has then aimed at applying phonological theories of spoken languages, such as autosegmental phonology, to sign structure; such study of the features of signs is sometimes called 'chirology' (from the Greek *cheir* 'hand'). Crucially for our purposes, the features or parameters of signs, i.e. the phonological units of sign languages, are usually considered to be handshape (hand configuration), location (place of articulation), orientation and movement (see Stokoe, Casterline & Croneberg, 1976; Brentari 1998, a.o.); they can recombine to form minimal pairs of signs. To these manual components, non-manuel signals (facial expression, head and eye movements) should be added. Also, note that some phonological models do not consider movement as a phonological prime as it is predictable from the locations, hand orientations and handshape features at the start and end of a sign (Hulst, 1993, a.o.).

DRY UGLY SUMMER

Figure 4 – signs contrasting in location only
(from Sandler 2003)

Dance notation is much less standardized than music notation, but as mentioned above, one famous system was invented by Laban in 1928, who was interested in the formal properties of movement. This notation aims at encoding the relevant aspects of movement by using symbols placed on a vertical staff read from bottom to top: as shown in Figure 5, the shape of the symbol indicates the direction of the movement; where the symbol is placed on the staff indicates the part of the body doing the movement; the shading of the symbol indicates the level of movement; and the length of the symbol indicates the timing of the movement. Other systems such as Sutton dance writing encode the same kind of parameters in a way that is more figurative and closer to music notation as can be seen in Figure 6.

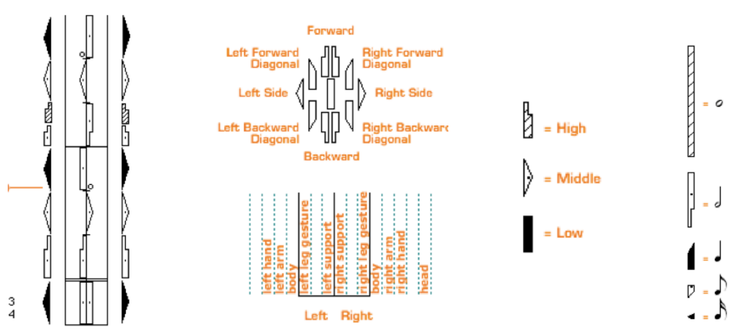

Figure 5 – Labanotation (1938)
(from http://dancenotation.org/lnbasics/frame0.html)

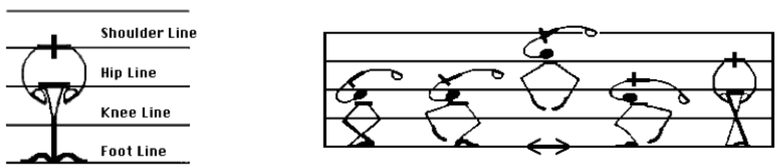

Figure 6 - Sutton dance notation (1974)
(from http://www.movementwriting.org/)

These two insights can be combined to determine the parameters of dance. The physical signal of dance consists of a change in position of the dancer body in space with respect to time: movement is physically created by an infinite sequence of continuous positions in space unfolding in time, as illustrated in Figure 7. Dance is thus characterized both by the parameters of the dancer position at a given time (cf. handshape and location in sign language) and the parameters of the movement itself created by their sequence in time (cf. symbols of Labanotation).

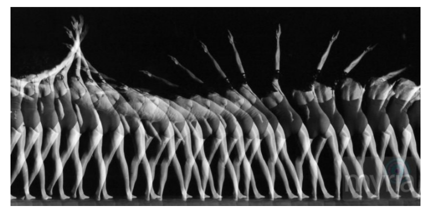

Figure 7. Movement as sequence of continuous positions
(from http://myria.com/maintaining-the-momentum-to-make-a-change)

First, the position of the dancer is characterized by its spatial situation: its absolute location in space - often a scenic place – (cf. location in sign language) and the relative position of the body parts or its configuration (cf. handshape in sign language, the stick figure in Sutton movement writing). Other properties of the position are its orientation (cf. orientation in sign language) and its point of contact with the floor or weight support (cf. level in Labanotation). Second, the movement itself has several properties: direction, speed, quality or dynamics (cf. Laban and Sutton systems). All these parameters of dance are summarized below and will be examined in more details when their relevance for the perceptual grouping units will be investigated in Section 3.

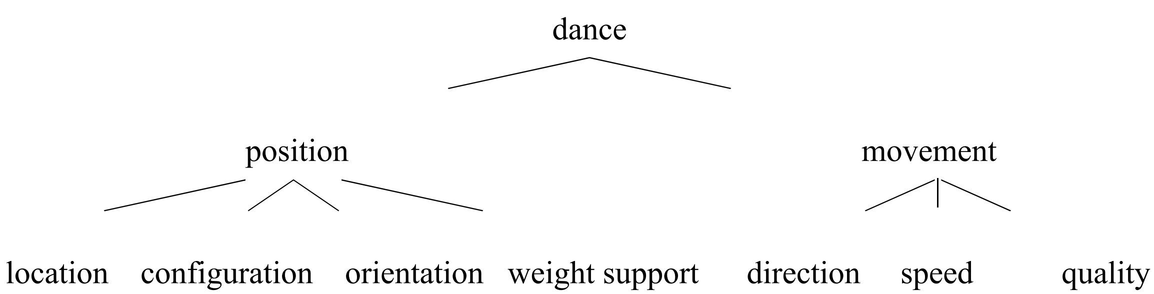

Figure 8. The parameters (minimal units) of dance

3. Grouping structure of dance

The parameters of dance that we have just defined (comparable to phonemes in language) will allow us to determine another type of units, i.e. the units of dance as perceived by the observer when unconsciously segmenting the sequence of movement into groups, i.e. they will allow us to define the grouping principles in dance, just like Lerdahl and Jackendoff (1983) did for music. Note that the main examples that will serve as illustrations are drawn from ballet and modern dance.[8]

To define groups, we will use the notion of position in the same way as Lerdahl and Jackendoff (1983) use the notion of note: just like a musical group is formed by one or more adjacent notes in the musical surface, the dance group is formed by one or more positions in the scenic space. This does not mean that the position is the relevant perceptual unit here, the group is (which can sometimes consist of one held position as we will see), which means that the units relevant for the grouping principles are not continuous (as the positions in the physical signal of movement[9]), but discrete. This can be compared to the units postulated for prosody in language (cf. Lerdahl 2001b): even if the speech signal is continuous, several types of prosodic units are usually distinguished, such as the syllable, the foot, the phonological word, the phonological phrase, the intonational phrase and the utterance (Selkirk 1986, a.o.); also, just as in music and in dance, one of the main ways to determine perceived prosodic grouping is to examine the acoustic cues for the boundaries, such as duration, fundamental frequency and intensity (see Shattuck-Hufnagel and Turk 1996 and Wagner and Watson 2010 for a review).

3.1. Grouping Well-formedness rules (GWFR)

As proposed by Lerdahl and Jackendoff (1983) for music, we can determine two sets of rules for the grouping component in dance: well-formedness rules and preference rules.

Well-formedness rules state the conditions that all possible dance grouping structures must satisfy. Below, I directly adopt the five group well-formedness rules of music proposed by Lerdahl and Jackendoff (1983). This reflects the fact that grouping as such is a general cognitive property.

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8 This is due to both methodological and pragmatic reasons: just as in linguistics, we usually start by examining one language in detail before making comparisons and generalizations, we also need to first examine specific types of dance; I choose ballet and modern dance as I have been practising them for a long time (and the comparison with music will also be more convenient as I am a classical pianist).

9 The positions of different dancers can be discontinuous in space, but a series of positions performed by different dancers does not *physically* constitute a movement even if it can be *perceived* as such in some specific cases: some choreographers play with this by giving the impression of movement when several dancers in line perform a movement one after the other following the same abstract line of space (cf. waves in a stadium; this is also what we actually see in Figure 7 given that the same dancer is represented as different bodies in this photograph).

Conversely, a sequence of positions performed by one body can be *perceived* as discontinuous even if they are *physically* continuous, either because of artificial elements triggering illusion, such as strobe light flashed in dance club that makes movement appear very jerky, or because of the movement quality itself as in street dances like popping. The idea of grouping structure is to extend the idea of perceived segmentation of the movement into discrete units to all cases of dance.

The first rule defines the basic notion of a group based on the idea of contiguity of position. It prevents configurations in which a set of discontinuous positions, at discontinuous points of time, is designated as a group. For instance, GWFR1 permits the groups shown in Figure 9, but it would prevent the positions {1, 5, 11} to be considered as forming a group together.

(1) *GWFR1*: Any contiguous sequence of positions, and only contiguous sequences can constitute a group.

```
 1    2   3    4      5    6      7       8        9      10    11
|----|---------------|------|-------------------------------|------|
```

Figure 9. Changement de pieds *(jump in which the feet change positions in the air) followed by* glissade *(lit. glide) in ballet*
(image from https://www.pinterest.com/pin/497507090057749846/)

The second rule expresses the intuition that a choreography is perceived as a whole rather than merely as a sequence of events.

(2) *GWFR2*: A dance constitutes a group.

The third rule provides the possibility of embedding groups, that is, the possibility of hierarchy, and the fourth and fifth rules state conditions on the embedding of groups within groups. GWFR4 expresses the ban on overlap and intersection, and GWFR5 prohibits grouping analyses in which part of a supergroup is not contained in any of the subgroups, which is illustrated in Figure 10.

(3) *GWFR3*: A group may contain smaller groups.

(4) *GWFR4*: If a group contains part of a Group G2, it must contain all of G2.

(5) *GWFR5*: If a group G1 contains a smaller group G2, then G1 must be exhaustively partitioned into smaller groups.

```
  1    2    3       4       5      6    7
|-----|---|                      |-----|----|
|-------------------------------------------|
```

Figure 10. An ill-formed grouping structure for a 'glissade' (violation of GWFR5)
(image from https://www.pinterest.com/pin/497507090057749846/)

It must nevertheless be noted that there are cases in which an observer has grouping intuitions that violate GWFR4 in licensing group overlap. As illustrated in Figure 11, position 5 is perceived both as the end of the *changement* and as the beginning of the *glissade*.

```
1    2   3    4     5    6     7      8      9     10   11
|----|--------------|------|------------------------------|------|
|-------------------|------|-----------------------------------|
```

Figure 11. Overlap

(image from https://www.pinterest.com/pin/497507090057749846/)

There are also cases in dance that are similar to what Lerdahl and Jackendoff (1983) call elision or Schlenker (2016) calls occlusion in music, which creates discontinuity. In particular, visual occlusion can occur when a (part of a) dancer hides another (part of a) dancer. Such cases are treated using specific transformational rules in Lerdahl and Jackendoff (1983) so as to maintain GWFR4 and prohibit unrestricted overlapping of groups. I leave a more detailed study of such cases in dance for further research.

Note that these rules are reminiscent of the Strict Layer Hypothesis in prosody (see Selkirk 1986, a.o.: a prosodic unit of a given level of the hierarchy is composed of one or more units of the immediately lower prosodic unit, and is exhaustively contained in the superordinate unit of which it is a part). In fact, these five grouping well-formedness rules are not specified in any direct way by the physical signal. That's why the class of grouping structures that is thereby defined can be just as well associated with a sequence of positions in space as with a sequence of pitch events or speech events.

Even though these rules rule out some ill-formed possible groupings as in Figure 10, they allow much more groupings than the intuitions of an observer would allow. For instance, most observers would probably not decompose the *glissade* move as in Figure 12 even if the represented grouping structure is well-formed according to the rules above: it seems counterintuitive to group with the first *plié* (lit. bending) in (2) the sliding of the first foot out into a *degagé* side in (3), but not to group the second *plié* in (6) with the closing of the second foot in (5) after the small jump in (4). We will explain this intuition based on principles of symmetry in Section 3.3. In fact, it seems even plausible that the positions 2-7 would not be decomposed, but perceived as one group.

```
1    2    3     4     5     6    7
|------------------| |-------------| |-----------|
|--------------------------------------------|
```

Figure 12. A well-formed, but dispreferred grouping structure for a 'glissade'

For this reason, I will follow Lerdahl and Jackendoff (1983) in defining preference rules besides well-formedness rules. While the latter only define formal conditions on grouping configurations, the former should express substantive conditions stating what parameters within the dance affect perceived grouping. These parameters do not necessarily reinforce each other to make the grouping intuition stronger; they can also be in conflict, resulting in ambiguous intuitions about grouping. That's why these rules are called preference rules, they aim at stating the factors that lead an observer to prefer a grouping over another, given that several groupings are possible.
The need for preference rules follows from the nature of intuitive judgments involved in the case of dance or music, as opposed to language. To build a linguistic theory, one crucial type of judgment that is used is grammaticality judgments, that is, the intuition of native speakers regarding whether or not a given string of words is a sentence in the language in question. Ambiguity, that is, whether a given string is assigned two or more structures with different meanings, does not play such a fundamental role. In dance however, just like in music, it is ambiguity that plays the most important role: it is much easier to construe dance in multiple ways because dance does not have specific meanings or functions like language; it is pure structure, in the sense that it is not associated with a specific meaning.[10] What is most relevant then is not to know whether a choreography or sequence of movements is well-formed ("grammatical"), but what is the most natural, coherent or preferred way to see it. Dance grammar should express these preferences among interpretations.

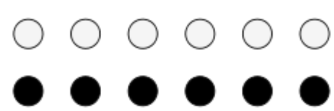
As in the case of music, we can distinguish between two types of preference rules, the local rules that determine the boundaries of groups, and the global rules that define larger-level grouping. We start with the former.

3.2. Grouping Preference Rules (GPR): local rules

Local rules determine how an observer unconsciously decides when a group ends and another one starts. This relies on the parameters of dance mentioned in section 2.3.

Most of the relevant local rules in dance are based on the general principle of similarity, one of the grouping principles defined by the psychologists of the Gestalt tradition based on intuitions about static visual grouping. According to the law of similarity, stimuli that physically resemble each other tend to be perceived as grouping together. For instance in Figure 13, the black dots are perceived as a group independent of the group formed by the white dots because of color similarity.

Figure 13. Gestalt's Law of similarity - Visual perception (from https://en.wikipedia.org/wiki/Principles_of_grouping)



[10] Or at least, music and dance semantics are based on very different principles than linguistic semantics. Schlenker (2016) proposes that a truth-conditional semantics can nevertheless be defined for music: he hypothesizes that the semantic content of an auditory percept can be identified with the set of inferences it licenses on its causal sources. I leave the exploration of dance semantics for further research.

In other words, two adjacent elements are perceived as belonging to different groups if they are not similar as compared to the other adjacent elements: group boundaries are transitions that are more distinctive than surrounding transitions. To determine local rules based on similarity in dance, that is, rules of local change, we thus need to define what kind of similarity is relevant in dance, given that it involves bodies changing positions in space across time.

3.2.1 Local rules based on spatial parameters (direction, orientation, weight, configuration)

First, several types of changes can be determined if we focus on the spatial dimension: the continuous series of positions taken by a moving dancer constitutes paths in space. Given that a human body is highly articulated, the physical properties of human movement are highly complex (see kinematics and kinesiology for studies of such properties based on anatomy and geometry of motion), but what concerns us here is the properties of perceived movement. In this respect, I hypothesize that there are two main types of perceived paths: the path traced in the performance area by each dancer moving across the scenic space (cf. locomotion in Lasher 1981); the paths made in space by each body part (head, limbs…) moving independently of the whole body (cf. contour motion in Lasher 1981). This distinction is due to human anatomy as well as gravity, which constrains the scenic space in a specific way: while the body of the dancer is subject to it, the body parts of the dancers do not appear to be constrained by it in the same way due to internal forces of the body that can compensate for it: a hand can move up and stay up for a very long time, while a whole body cannot remain up in the air for a long time, but only for brief leaps. This means that observers perceive two types of space: a fully three-dimensional space relevant for body parts, especially arms and hands (other body parts cannot have a full use of the space due to anatomical constraints: a head cannot completely move on itself for instance), and a quasi two-dimensional space relevant for the whole body, which mainly moves on the horizontal plane and can only use a restricted range of the vertical dimension due to gravity constraints.[11]

Moreover, these two types of space are oriented in different ways: specifically, absolute and relative points of reference do not have the same status in each case. In the case of the space relevant for the whole body, absolute points of reference, determined by the orientation of the room and fixed elements such as the audience and the stage, are the main factors for determining the directions: motions are mainly perceived as room-relative, e.g. stage-backward or stage-forward. This has been codified in certain types of dance as represented in Figure 14 for ballet (Vaganova school) and in Figure 15 for ballroom dancing.

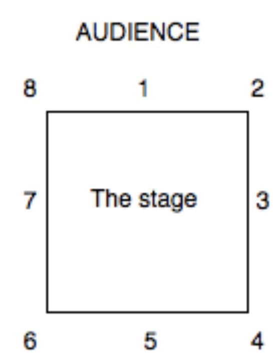


Figure 14 – Relevant directions according to the Vaganova technique of ballet
(from http://www.tightsandtiaras.com/2010/05/french-4-directions/)

[11] Gravity constraints are not relevant in specific kinds of dances that do not involve the whole body, such as finger dance (e.g. https://www.youtube.com/watch?v=pXZS6-QALP8).

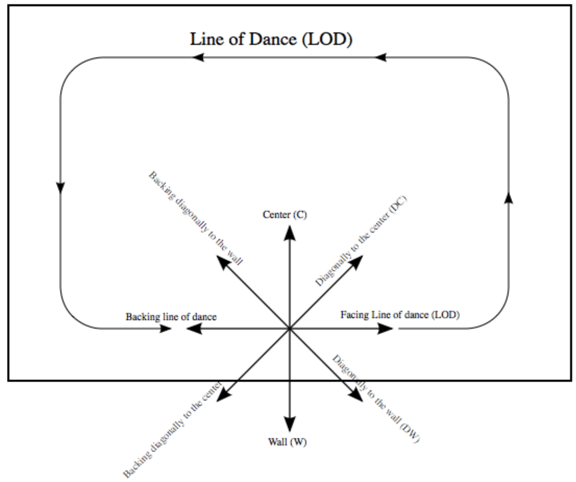


Figure 15. Directions of movement with respect to the room in ballroom dancing (from https://en.wikipedia.org/wiki/Direction_of_movement_%28ballroom_dancing%29)

The relativity of movement with respect to the room as a fixed point of reference is sometimes reflected in the vocabulary used in dance. For instance in ballet, if a step is traveling forward towards the audience, it is called *en avant* ("forward") or *en descendant* ("going down");[12] the reverse holds for traveling backward, *en arrière* ("backward") or *en remontant* ("going up"). When the dancer is traveling in a diagonal across the stage, it is called *en diagonale*. Note nevertheless that even if directions of whole body movement are mainly perceived as relative to the reference points of the room, they can also depend on other points of reference such as objects (cf. pole dance) or other dancers on the stage (this is particularly relevant for ballroom dancing where the direction of movement with respect to the partner is crucial).

In the case of the space relevant for body parts, directions are on the contrary mainly perceived as body-relative: for instance, a hand or a foot is rather perceived as moving towards or away from the body trunk, than towards or away from the audience. This is also reflected in the vocabulary of ballet: when a step is performed in front of the body of the dancer, it is called *devant* ("forewards") regardless of the body's direction, and conversely, when a step is performed to the back of the dancer, it is called *derrière* ("backwards"). Also, if a step is performed to the side in relation to the dancer's body, it is called *à la seconde* ("in second"; this refers to the second of the five basic positions in ballet, where the feet are separated to each side).

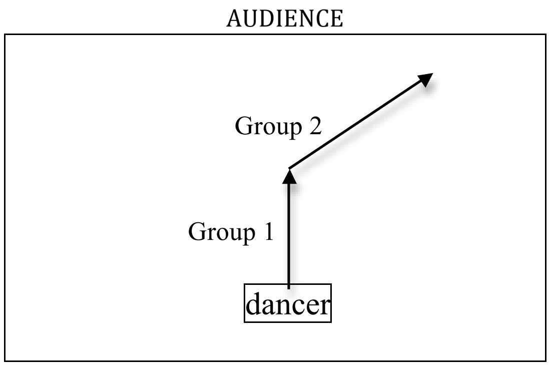
Thus, as summarized in Table 2, the body movement is mainly perceived relative to the reference points of the room; it can have any direction on the horizontal plane and occurs in a limited three-dimensional space due to the restriction imposed by gravity on the vertical plane. The movement of the limbs is however three-dimensional and mainly perceived as body-relative.

	Whole body	Body parts
Perceived dimension of space	Quasi two-dimensional	Fully three-dimensional
Reference frame for movement	Mainly room-relative	Mainly body-relative

Table 2. Two types of perceived movement with respect to space

[12] This terminology is due to the fact that traditional European theater stages are raked, that is, they typically sloped upward away from the audience to improve the view from the audience.

Crucially, this means, with respect to grouping structure, that any change of direction determines a group boundary: each time the movement path - of the whole body or of the body parts – deviates, it starts a new sequence. For instance, if the dancer is traveling stage forward and then turns to move in diagonal, a group boundary is formed: this is made clear by the abstract pattern traced by the movement on the floor, as exemplified in Figure 16. Similarly, if the hand of a dancer is moving away from the body and then turns as illustrated in Figure 17, we can also perceive two movement groups due to the change of direction.



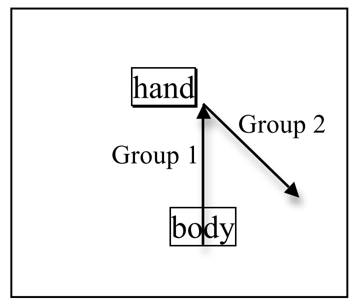


Figure 16. Change of direction of the whole body

Figure 17. Change of direction of a hand

This defines the first local preference grouping rule GPR1 (for an illustration from a real performance, see excerpt 12:58-13:10 from *Jewels Ballet* by Balanchine: http://www.youtube.com/watch?v=LuKekvgdkiE&t=12m58s).

(6) *GPR 1* (change of direction): consider a sequence of positions p_1, p_2, p_3, p_4, p_5, p_6. The transition p_3-p_4 may be seen as a group boundary if the path formed by p_1-p_2-p_3 does not have the same direction as the path formed by p_4-p_5-p_6.

Furthermore, it is not only the space in which the dancer moves that is oriented and thus determines different directions of the movement, the body of the dancer itself is also oriented: it has an intrinsic front, back, right, left, top and bottom as represented in Figure 18.

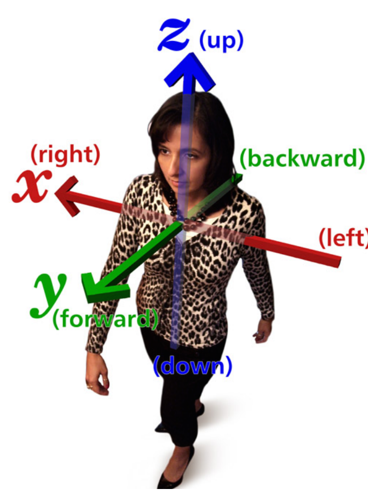


Figure 18. The intrinsic orientation of the human body (from https://en.wikipedia.org/wiki/Relative_direction)

This has also been exploited in ballet where the directional orientation of body facings, known as the directions of *épaulement*, is conceived according to a square with dimensional orientations directed toward the edge midpoints, and diagonal orientations directed toward the corners as shown in Figure 19. Diagonal facings (i.e. 45° to the front of the stage space) are indicated with the French terms *croisé* (legs crossed), *effacé* or *ouvert* (legs open), *épaulé* (front shoulder crossing the body) and *écarté* (leg wide to the side). Dimensional facings are referred to with the French terms *en face* (facing the audience) or *de côté* (facing the side of the room).

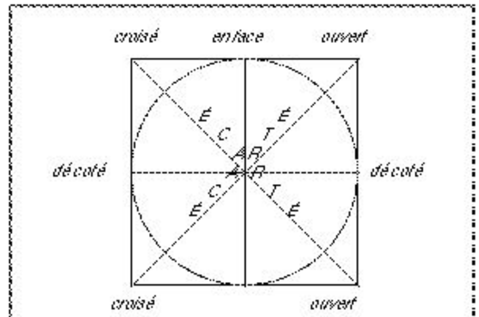


Figure IVA-16. "Personal square" for orientation of body facing (adapted from Royal Academy, 1991, p. 1)

Figure 19. Directional orientation of body facings in ballet
(from Longstaff 1996: Figure IVA-16)

Importantly, the orientation of the body is independent from the direction of movement: a dancer can move stage-forward while facing the audience or facing the side of the room or any other direction (see excerpt 8:10-8:20 from *The Crystal Palace* by Balanchine for a change of orientation without change of direction: http://www.youtube.com/watch?v=bh5lkABh2ww&t=8m10s). The only constraint on the relation between body orientation and movement direction is the position of the eyes on the face: the dancer can fully see where (s)he is moving only if direction and orientation match. But mismatches are physically possible: a dancer can move stage-backward even if (s)he is facing the audience (speed and frequency of such movements are however affected). Note that this distinction between direction and orientation is less perceptible for body parts since for anatomical reasons, only some body parts are concerned: almost exclusively the hand can move in any direction independently of its orientation; for instance, the hand can move away from the body while facing the body or facing away of the body (that's why orientation can be highly relevant in sign language), given that it has an intrinsic orientation (it has a face and a back).

The relevance of orientation in movement defines a second type of local rule: orientation change; in other words, similarity in body orientation determines grouping (as illustrated in *Einstein on the beach* by Lucinda Childs: http://www.youtube.com/watch?v=sMb2f_-m7iM&t=0m2s).

(7) *GPR 2* (change of orientation): consider a sequence of positions p_1, p_2, p_3, p_4. The transition p_2-p_3 may be seen as a group boundary if the orientation of the body (part) in p_1-p_2 is different from the orientation of the body (part) in p_3-p_4.

The specific constraint imposed by gravity[13] determines another type of similarity. We mentioned that because of gravity, the dancer does not have a lot of range to move on the vertical plane and thus can only move in a three-dimensional space that is highly

[13] As mentioned in footnote 11, this does not hold for specific types of dance that do not use the whole body such as finger dance.

restricted on the vertical dimension. In terms of perception, this property makes salient what part of the body is in contact with the floor and supports the weight of the body since it is perceived as the point of stability.

Most of the time, legs are in contact with the ground, as in the usual standing position, and the weight can shift from one foot to the other. Also, it is not necessarily the foot as a whole that touches the floor, but it can be only one part of it, e.g. when moving on tiptoe or pointe shoes in ballet; conversely, more than the foot can touch the floor, that is, the knee or even the full leg in cases of splits for instance.

Furthermore, the body can be upside down in some types of dance (e.g. break dance, contemporary dance), that is, only hands (both or only one) support the body. In break dance, it is even possible for the head only to be on the floor. Some dances also allow the trunk (back, belly, bottom) to touch the ground (cf. contemporary dance floorwork). Finally, the dancer can be completely up in the air with no contact with the floor in cases of leaps or partner lifts. In sum, gravity and anatomical constraints determine what part(s) of the body can be on the floor to support the dancer, and dance styles usually codify what is allowed; for instance, only legs (foot, knee or full leg sometimes) can touch the floor in ballet. Several of these options are illustrated in Figure 20.

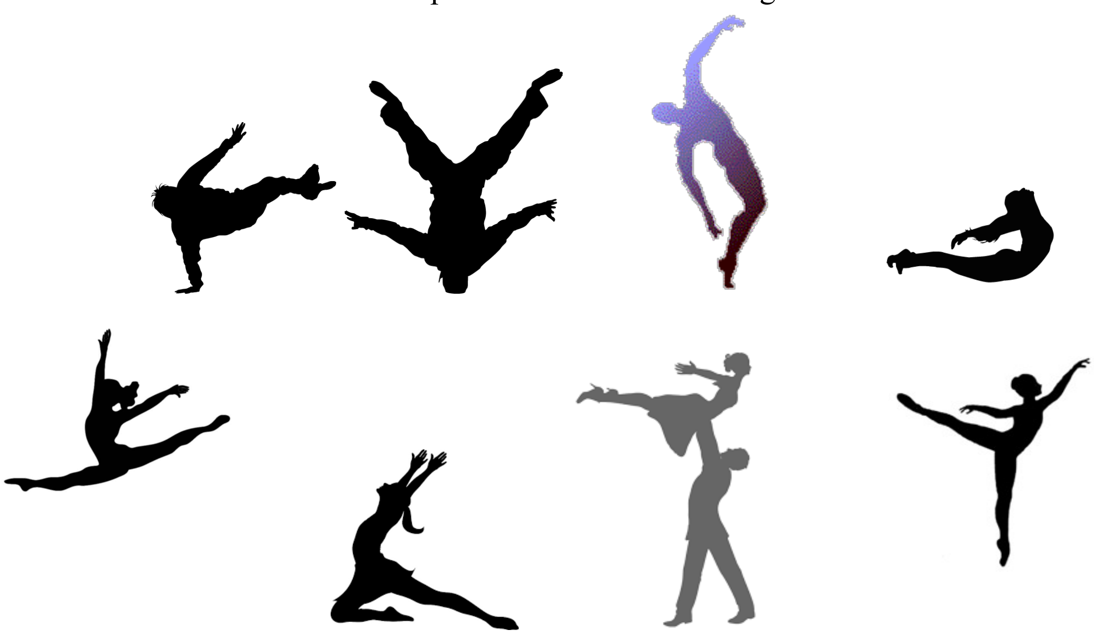


Figure 20. Different points of contact with the ground
(from www.clipartpanda.com; www.clipartof.com; www.clipartbest.com)

Based on these observations, we can define a third local rule: each time the weight of the dancer is supported by a different body part, this delimits a group boundary. For instance all movements performed on the ground (floorwork) are perceived as similar as compared to movements performed standing up, so that these two types of movement constitute different groups (see e.g. excerpt 6:30-7:10 from *Petite Mort* by Jiří Kylián http://www.numeridanse.tv/en/video/1050_petite-mort). In other words, movements performed at different levels (high, middle, low) constitute groups.

(8) *GPR 3* (change of contact point with the floor/weight shift): consider a sequence of positions p_1, p_2, p_3, p_4. The transition p_2-p_3 may be seen as a group boundary if the body part in contact with the floor in p_1-p_2 is different from the body part in contact with the floor in p_3-p_4.

Note that weight shift is often accompanied by other changes of parameter such as change of direction (GPR 1) or change of moving body part (see GPR 4 below). GPR 3 is not redundant though, as it defines a grouping that extends until the contact point with the floor changes again, and such a group could not be defined using another single rule. In that sense, GPR 3 may be considered as a higher-level grouping.

To finish on types of group changes that mainly involve the spatial dimension of dance, the moving entity itself is subject to change: the whole body of one dancer can move, or only parts of his/her body, or the bodies of several dancers simultaneously. Changes are perceived each time the changes of position affect a different set of entities: at the level of the whole scene, when a dancer joins or leaves the dance (see e.g. excerpt 12:20-12:30 http://www.youtube.com/watch?v=ru0ruEZeqa0&t=12m20s from *Serenade* by Balanchine); at the level of one dancer, when a body part stops or starts moving. This defines a fourth local grouping rule.

(9) *GPR 4* (change of moving entity): consider a sequence of positions p_1, p_2, p_3, p_4. The transition p_2-p_3 may be seen as a group boundary if the set of body(s) (part(s)) affected by the change of positions p_1-p_2 is different from the set of body(s) (part(s)) affected by the change of positions p_3-p_4.

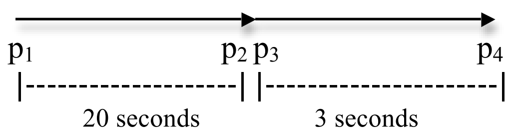
Moreover, given the central status of the face in the expression of emotion, we can determine a specific rule for it: movements performed with a similar face expression can be perceived as forming a group. This is particularly relevant in Indian dances: Indian classical dances such as Kathakali, Bharathanatyam and Kutiyattam, use nine different facial expressions (Navarasa) to express nine moods (erotic/delight, heroic/heorism, pathetic/sorrow, humourous/laughter, wonderous/wonder, fearful/fear, odious/disgust, terrible/anger, peaceful/peace). A change of expression can thus mark a group boundary (as illustrated by excerpt 0:30-0:45 from a Bharatanatyam performance based on the composition in Malayalam *Neelakkarmukil Varnan* http://www.youtube.com/watch?v=27iUzw-kMiw&t=0m30s). Even if facial expressions are rarely codified in dances, they are always used by interpreters to express emotions, and observers are very sensitive to them.

(10) *GPR 5* (change of facial expression): consider a sequence of positions p_1, p_2, p_3, p_4. The transition p_2-p_3 may be seen as a group boundary if the facial expression in p_1-p_2 is different from the facial expression in p_3-p_4.

3.2.2 Local rules based on spatio-temporal parameters (speed, dynamics)

Further types of similarity, and thus other types of local grouping rules, can be determined if we take into account both dimensions of space and time. In particular, just like in music, changes of speed mark boundaries between groups: intuitively, a part of a dance involving slow movements and another part involving quick movements are perceived as two different sequences. This can be formalized in a simple way using the notion of distance, that is, the length of the path covered by the body (part) of the dancer during a certain amount of time. For instance, as illustrated in Figure 21, if a dancer covers a given distance on the scene in 20 seconds, and then without changing anything else (i.e. direction, orientation, moving entity…), (s)he covers the same distance in 3 seconds by accelerating the movement, observers tend to perceive such a movement as two sequences because they have been performed at different speeds. Note that this is codified in some dances: in ballet, slow, sustained movements are called *adage*, while quick, light jumps are called *allegro*. This is generalized in the sixth grouping rule in (11) (see examples in excerpt 1:55-2:32 from *Raymonda* variation by Rudolf Noureev http://www.youtube.com/watch?v=99b2SvdhSQQ&t=1m55s and excerpt 2:30-2:55 from *La Cigarette* in *Suite en Blanc* by Serge Lifar http://www.youtube.com/watch?v=6PI8QA1dWHw&t=2m30s). Of course, the rule could be formulated in different ways, e.g. by reversing the role of distance and time, that is, by considering the distance covered in the same amount of time, rather than the time taken to cover the same distance; this is equivalent.

Figure 21. Change of speed



(11) *GPR 6* (change of speed): consider a sequence of positions p_1, p_2, p_3, p_4, with p_3-p_4 forming a path of the same length as the path formed by p_1-p_2. The transition p_2-p_3 may be seen as a group boundary if the amount of time taken to cover the path p_1-p_2 is different from the amount of time taken to cover the path p_1-p_2.

An extreme case of change of speed is pause in the movement, which is highly salient in perception; every time the movement stops, this determines a group boundary as defined in grouping preference rule 7; conversely, another boundary is formed when the movement starts again (for illustrations, see excerpt 1:55-2:17 from *Sleeping Beauty* variation by Rudolf Noureev http://www.youtube.com/watch?v=3963IDhl1zw&t=1m55s and excerpt 0:30-1:00 from *Solo* by William Forsythe http://www.youtube.com/watch?v=hH7yAZRdkFs&t=0m30s). This means that the pause itself, or a held position, can be perceived as a sequence in the movement. Note that we can distinguish between a position held with effort, which would correspond to a sustained note in music, and a position held without effort, which would correspond to silence in music (see Eitan and Granot 2006 for an empirical investigation of how changes in musical parameters are associated with changes in movement).

(12) *GPR 7* (pause): consider a sequence of positions p_1, p_2, p_3, p_4. If the length of p_2, i.e. the amount of time during which p_2 is held, is longer than the length of p_1 and

p_3, the transition p_1-p_2 may be seen as a group boundary as well as the transition p_2-p_3.

Another type of similarity involving both dimensions of space and time concerns the quality or dynamics of the movement, which depends on release of energy and force. The intensity of force that is used (from gentle to strong) and the way the energy is released (e.g. sudden, slow, strong, sag, forceful, sustained, collapse, swing, jerky) affect the perceived quality of movement. Instructional trainings of modern dance mention several types of movement qualities depending on the degrees of energy expended, such as swinging, sustaining, percussing, suspending, vibrating or collapsing. For instance, a steady application of energy produces a smooth movement; an intermittent application of energy results in a percussive or vibratory quality; a movement having the quality of a swing gives way to the downward pull of gravity following an initial application of energy. From the point of view of Laban's effort theory, there are 4 main factors that make up the dynamics of movement: space (direct or indirect), time (sustained or sudden), weight (light or strong) and flow (free or bound). The combination of these 8 possible ways of executing any movement creates variations in its dynamic. To give an example of the differences between dynamics, Laban gives a name to 8 basic actions that would result from these combinations: punching, floating, pressing, flicking, gliding, slashing, dabbing and wringing (see http://www.artsalive.ca/en/dan/make/toolbox/elements.asp#dynamics for illustrations). Different types of dance favor different movement qualities. For instance, popping is a kind of street dance that is based on the technique of quickly contracting and releasing muscles to cause a "pop" in the dancer's body: movement in popping is thus mainly jerky. But in general, many types of movement quality co-occur within the same dance; for instance, belly dance involves both percussive and fluid movements of the hips; ballet can also involve both smooth and more jerky movements (see excerpt 6:33-6:54 http://www.youtube.com/watch?v=LuKekvgdkiE&t=6m33s from *Jewels* ballet by Balanchine). Moreover, movement dynamics can be decided by the choreographer or by the dancer, whose personal way of moving can have an important influence on the movement quality. In any case, movement dynamics is highly perceptible so that an observer will tend to group movements together based on similarity in their quality. This constitutes a eighth grouping rule.

(13) *GPR 8* (change of dynamics/quality): consider a sequence of positions p_1, p_2, p_3, p_4 with only p_2 and p_3 being contiguous. The transition p_2-p_3 may be seen as a group boundary if the quality of movement between positions p_1-p_2 is different from the quality of movement between positions p_3-p_4.

All eight grouping preference rules that we have just defined are thus based on the general principle of similarity: transitions between positions form group boundaries when they are more distinctive than surrounding ones, and this can be so because of change of dynamics, speed, moving entity, face expression, contact point with the floor, orientation or direction, which correspond to different types of similarity relevant in dance. A second general principle of grouping that can determine local boundaries in music according to

Lerdahl and Jackendoff (1983) is the principle of proximity: notes closer to each other in time are perceived as forming a group. Given that positions are continuous in space while notes do not have to be continuous in sound (they can be separated by silence), the equivalent principe was captured in terms of similarity in speed (GPR 6).
Proximity can nevertheless be relevant in dance at a higher level, namely when taking into account several dancers, given that most choreographies involve more than one dancer. At that level of perception, grouping in dance boils down to visual grouping in the Gestalt tradition. According to the law of proximity, objects that are close to each other tend to be perceived as forming a group: for instance in Figure 22 involving 36 circles, we perceive them as three different groups of 12 circles.

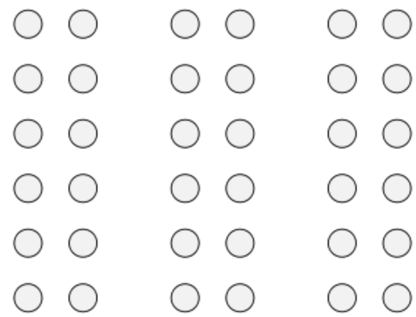


Figure 22. Gestalt's Law of proximity - Visual perception (from https://en.wikipedia.org/wiki/Principles_of_grouping)

Similarly, in a dance involving several dancers, an observer will group together dancers that are close together. Note, however, that this is not a specific grouping rule of dance because it does not take into account movement but only the spatial organization of dancers on the stage.

Finally, given the many different factors determining potential group boundaries that we have just proposed and the complexity of human movement due to our anatomy, we could worry about the multiplication of group boundaries, which would threaten their perceptibility and the existence of grouping itself. To prevent this, I add a ninth grouping preference rule similar to the general formulation of GPR 1 in Lerdahl and Jackendoff (1983: 43). This rule prevents excessive segmentation into groups as very small-scale grouping perceptions are marginal.

(14) *GPR 9*: avoid analyses with very small groups – the smaller, the less preferable.

3.3. Global GPR: intensification, parallelism, symmetry, closure

Hierarchy needs to be added in our system of dance grouping. This can be done by supplementing local detail rules with global rules of grouping.
The first of these higher-level grouping rules, inspired by Lerdahl and Jackendoff (1983), almost directly encodes hierarchy:

(15) *GPR 10* (intensification): When the effects picked out by the local rules of change (GPR1-GPR8) are relatively more pronounced, a larger-level group boundary may be placed.

Applying this rule to GPR1 (change of direction), this means that in several sequences of positions all determined by changes in direction, a second level of grouping will be perceived based on stronger changes of direction as illustrated in Figure 23.

Figure 23. Two levels of grouping based on changes of direction

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p1     p2     p3     p4
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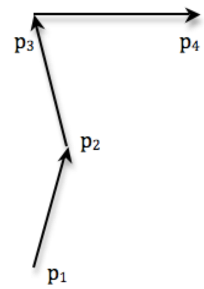


Here, the local rule GPR1 correctly predicts the 3 groups indicated in the first line of grouping (p_1-p_2 ; p_2-p_3 ; p_3-p_4): each change of direction marks a group boundary. However, GPR1 does not say anything about the second level of grouping (p_1-p_3 ; p_3-p_4), but GPR 10 does: because the change of direction at p_3 is more intense that the other changes of direction, this marks a larger-level group boundary. Intuitively, an observer will perceive the first two groups as one higher-level group where the dancer moves in one direction, say, toward the audience (in two sequences), and the next group as another higher-level group where the dancer moves toward the side of the stage (in one sequence).
The same holds for all local grouping rules: every time the change is more pronounced, it marks a higher level grouping boundary, thus establishing a hierarchy in the grouping structure of the dance.

There is a second type of higher-level grouping rule based on local rules: parallelism. Recall that local rules mark boundaries each time similarity within a set of positions is broken, and we determined 8 parameters that can break the similarity (direction, orientation…etc). We can now assume that similarity holds at a higher level: similarity of the changes themselves is also relevant for grouping; every time the changes of moves in a complex sequence of movement are similar to the changes of moves in another complex sequence of movement, this determines two higher-level groups. This is particularly salient if the changes with respect to all parameters are identical in the two sequences of movement, namely if there is repetition of the same sequence: a series of movements is perceived as a group each time it is repeated, as illustrated below (for examples from real choreographies, see excerpt 12:35-12:45 from *Dances at a Gathering* by Jerome Robbins http://www.youtube.com/watch?v=X7irDmS3eig&t=12m35s and excerpt 2:55-3:06 from *Rosas dans Rosas* by Anna Teresa De Keersmaeker http://www.youtube.com/watch?v=51fxJLjs3Yc&t=2m55s).

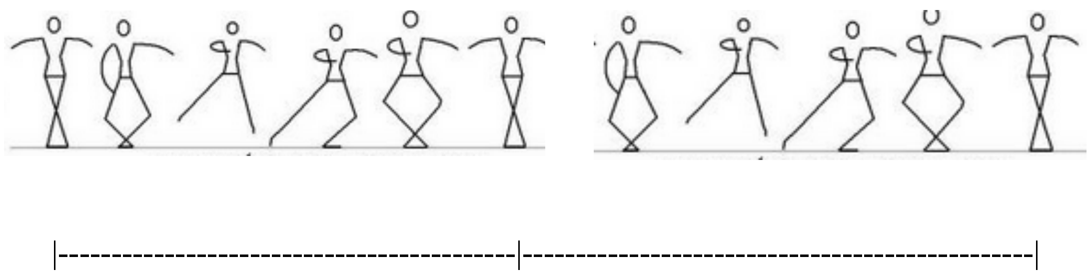


Figure 24. Repetition as higher-level grouping
(image from https://www.pinterest.com/pin/497507090057749846/)

Grouping is also perceived if the changes are not identical with respect to all parameters, but only to some of them. To take GPR 1 as an example again, if a series of positions includes a certain number of changes of direction, and another series of positions includes the exact same changes of direction in the same order, these two series are perceived as two sequences of movement, even if the other parameters (orientation …etc) do not change in the same way in the two sequences. This is illustrated in Figure 25: the exact same sequence of changes of direction happens twice, which leads the observer to construct two groups based on this similarity: the path traced by the dancer on the floor forms a figure between p_1 and p_2 that is repeated between p_2 and p_3.

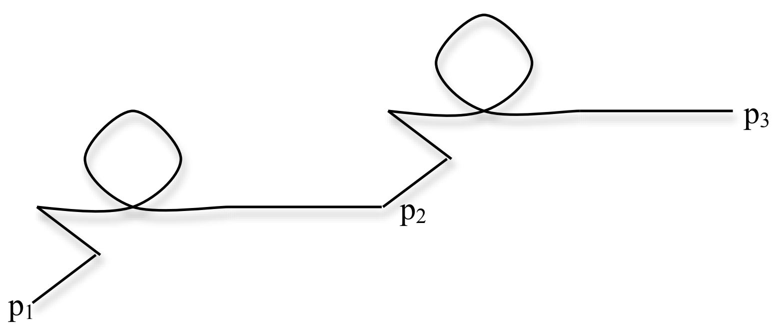


Figure 25. Parallelism as higher-level grouping

This principle of grouping based on similarity of sequences of changes can be called parallelism by analogy to the Gestalt principle of parallelism illustrated in Figure 26: elements that are parallel to each other are seen as more related than elements not parallel to each other.

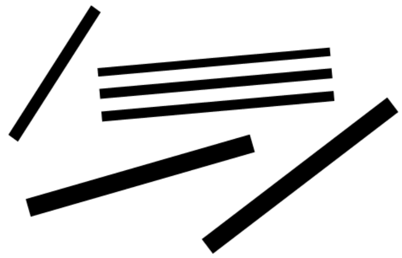


Figure 26. Gestalt's perceptual principle of parallelism
(from https://www.smashingmagazine.com/2014/03/design-principles-visual-perception-and-the-principles-of-gestalt/)

This defines a second global preference rule of grouping:

(16) *GPR 11* (parallelism/repetition): When a series of changes is repeated with respect to some (parallelism) or all (repetition) parameters (defined in the local rules), it constitutes a group.

Just as there is a general preference for parallelism, there is a general preference for symmetry in the grouping structure. According to the Gestalt's law of symmetry, the mind perceives objects as being symmetrical and forming around a center point as illustrated in Figure 27.

Figure 27. Gestalt's perceptual principle of symmetry
(from https://en.wikipedia.org/wiki/Gestalt_psychology)

Similarly, two sequences of moves are perceived as one group if they can be construed as symmetrical. Just as we can distinguish between two kinds of direction as we have seen (room-relative and body-relative), at least two types of symmetry are relevant in dance: symmetry based on the anatomy of the human body and symmetry based on the structure of the room. Concerning the former, given that the right and the left sides of a human body are mirror images of each other, two sequences of moves can be perceived as symmetrical - and thus form a higher-level group - if one is performed with a right body part (especially foot or/and hand), and the other one is identical and performed with the corresponding left body part. For instance, if the ballet step *sissonne* illustrated in Figure 24 (where it is repeated twice with the right leg) is performed once with the right leg, a second time with the left leg, a third time with the right leg again and a fourth time with the left leg again, the four sissonnes (construed as four groups based on the principle of repetition) are construed as two higher-level groups based on symmetry (right/left; right/left) (for an illustration involving a more complex set of left/right symmetrical movements in ballet, see excerpt 0-00:24 from *Grand Pas Classique* by Victor Gsovsky https://www.youtube.com/watch?v=Cv9Yms5Q3Gg&t). Moreover, even if the human body is not physically symmetrical along the front/back sides, two sequences of movement can be perceived as symmetrical if one is performed in front of the body, and the other one on the back: in particular, combinations of steps are said to be “reversed” in ballet when after performing a step with the front leg, a similar step is performed with the back leg as shown in Figure 28.

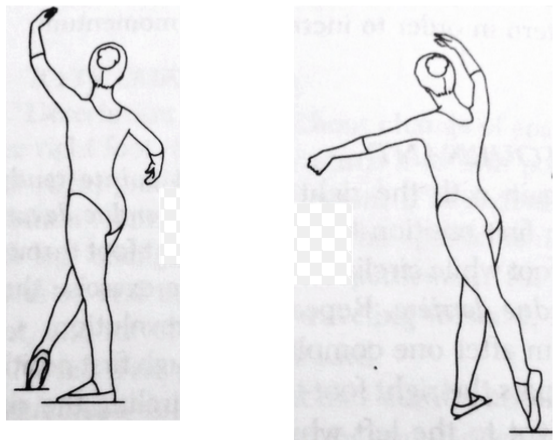


Figure 28. Reversal of ballet combination perceived as symmetrical
(https://classconnection.s3.amazonaws.com/667/flashcards/4886667/png/croise-144487A8CE145993192.png)

Concerning the second type of symmetry, the stage can be perceived as symmetrical along the left/right dimension and the back/front dimension, which can lead the observer to perceive symmetrical groups with respect to direction or orientation of the movement. For instance, if a sequence of steps is performed towards the right of the room, and then the same sequence of steps is performed towards the left of the room, these two sequences are perceived as symmetrical and thus constitute a higher-level group. The same holds if the dancer is facing the audience while executing a series of steps, and (s)he is then facing away from the audience while executing the same series of steps. Often, symmetries with respect to the body and with respect to the room are combined (cf. excerpt from *Grand Pas Classique* mentioned above).

(17) *GPR 12* (symmetry): When two sequences of steps are perceived as symmetrical (relatively to the body or to the room), they constitute a group.

Another perceptual principle defined by the Gestalt tradition can be transposed into dance to determine higher-level grouping: the principle of closure. According to the law of closure, when seeing a complex arrangement of elements, we tend to look for a single, recognizable pattern. This is illustrated in Figure 29, where we tend to “close” a circle and a rectangle, thus perceiving two groups of elements.

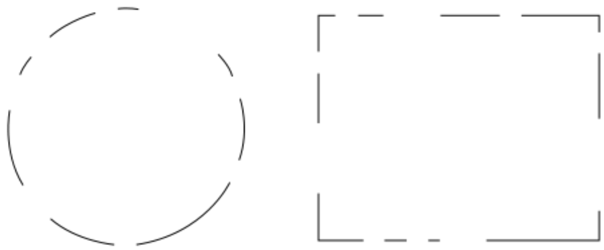


Figure 29. Gestalt's perceptual principle of closure
(from https://en.wikipedia.org/wiki/Gestalt_psychology)

This principle of closure is relevant in the perception of the path traced by the dancer when moving across the floor: each time this path constitutes a closed form, that is, each time the dancer comes back to a previous position in space, a group is formed. This is shown in Figure 30: four groups are determined based on GPR 1 (change of direction), that is p_1-p_2, p_2-p_3, p_3-p_4 and p_4-p_1, and based on the principle of closure, these four groups constitute a higher-level group because the abstract path traced by the dancer on the floor forms the closed figure of a rectangle. This defines the fourth global rule in (18).

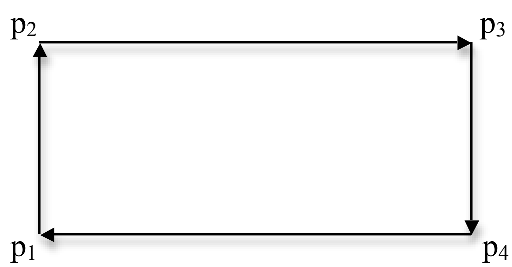
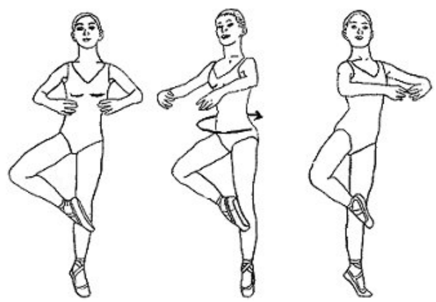


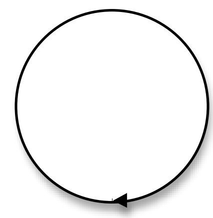
Figure 30. Closure of path as higher-level grouping principle

(18) *GPR 13* (closure): if the path formed by p_1-p_2-p_3-p_4 (non contiguous) draws a closed figure, this set of positions (and the intermediate ones) constitutes a group.

More generally, each time the dancer comes back to a previous position in space (e.g. p_1 in Figure 30) or to a previous pose (e.g. the neutral standing position, or the neutral position of each body part), the observer has a feeling of closure that leads him/her to represent this as a boundary of higher-level group. This is especially salient in the case of circular movement as illustrated in Figure 31; no change of direction can be perceived when a dancer moves following a circular path on the floor since the curve is continuous; but once the full circle is traced, this is perceived as a group (see excerpt 3:14-3:30 from *Sleeping Beauty* variation by Rudolf Noureev http://www.youtube.com/watch?v=3963IDhl1zw&t=3m14s and excerpt 5:5-5:20 from *In the Middle somewhat elevated* by William Forsythe https://www.youtube.com/watch?v=NghGmjtxeak&t=5m5s); the same holds if the circular path is traced by a body part in the air. Similarly, when the dancer performs a turn, this is perceived as a group; this is illustrated with a ballet *pirouette* in Figure 31, but turns are commonly realized in many types of dance and can either affect the whole body of the dancer or some body parts (hands, head, hips, foot).



a. *Pirouette* ('turn') in ballet
(http://ele.cy.tripod.com/pir2.jpg)



b. Circular path on the stage

Figure 31. Circular movement as grouping structure

Finally, note that just as for local rules, these global rules of grouping also hold for the organization of the dancers in space, when a choreography involves more than one dancer. For instance, a choreographer such as Balanchine makes an important use of symmetry in his choreographies (see *The Crystal Palace* for an illustration http://www.youtube.com/watch?v=bh5lkABh2ww&t=0m40s).

3.4. Hierarchy

The relevance of global rules of grouping shows that grouping structure is hierarchical: local rules indicate the lowest levels of grouping, while global rules determine higher levels of grouping. Moreover, the principles of intensification, parallelism, symmetry can apply recursively, and thus yield several hierarchical levels of grouping. This is illustrated in Figure 32, where the repetition of the same sequence of steps (*sissonne*, cf. Figure 24) four times can be represented as 3 levels of grouping.

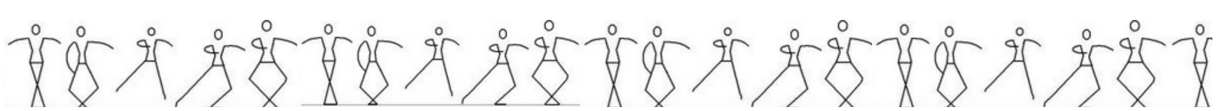


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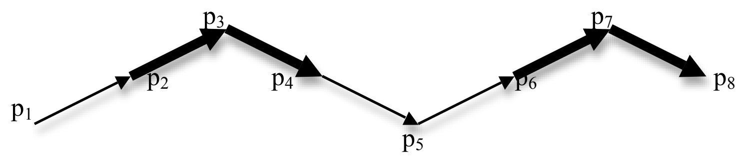
Figure 32. Recursivity (in the case of repetition)

Furthermore, we could wonder whether there is a hierarchy among local rules: local rules may have different strengths so that some prevail over others. As opposed to language, competition among conflicting principles is indeed a normal feature in the determination of dance structure. The same holds in music as illustrated below with a toy example from Jackendoff and Lerdahl (2006: 39).

Figure 33. Conflicting grouping principles in music

The two organizational principles at stake here are similarity in pitch and proximity in time. Line (a) involves no conflict, but the four groups are determined by similarity (in fact identity of) pitch. The notes in lines (b) and (c) can however be grouped in two different ways depending on whether we adopt similarity in pitch as a primary grouping principle or proximity in time; the latter is adopted in line (b), and the former in line (c). The question is whether observers in general would preferably adopt the same grouping strategy in such cases or whether the music is ambiguous. In the first case, there are two ways of resolving the conflict: either one principle always prevails over the other, for instance, proximity in time is more important than similarity in pitch for grouping as could be suggested by line (b); or there is no hierarchy between the two principles in general, but it depends on the intensity of each one, that is, how the similarity in pitch compares with the proximity in time; thus in line (c), the grouping is based on similarity in pitch because the differences in pitch are more important than the distances in time (this supposes that we can make such comparisons).
The exact same questions hold for dance. An open issue (to be determined empirically) is whether the 8 parameters identified for local grouping rules are organized into a hierarchy; in other words, how are conflicts in grouping principles resolved? Figure 34 illustrates a conflict between GPR 1 (change of direction) and GPR 6 (change of speed: the thinner arrow indicates slower speed and the thicker one indicates higher speed). The question is whether observers would organize such a sequence of moves primarily based on GPR 1 (p_1-p_3; p_3-p_5; p_5-p_7; p_7-p_8), on GPR 6 (p_1-p_2; p_2-p_4; p_4-p_6; p_6-p_8), on both of them without hierarchy (p_1-p_2; p_2-p_3; p_3-p_4; p_4-p_5; p_5-p_6; p_6-p_7; p_7-p_8), or whether it would depend on the intensity of each one; unless the dance structure is simply perceived as ambiguous here. Experimental work (in progress) should be able to answer this kind of question.

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? |------------------|-----------------|------------------|--------|
? |----------|-----------------|------------------|-----------------|
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Figure 33. Conflicting grouping principles in dance

3.5. Headedness

The existence of hierarchy in grouping structure raises the question of headedness: can we assign heads to dance groups? In linguistic syntax (and morphology), the head of a constituent is the element that determines the properties of the constituent; in particular, it determines the category and the distribution of the constituent, and what the head selects determines the formation of the constituent: for instance, the verb determines the properties of the Verb Phrase (VP). This notion of head is not applicable to dance or music, where the notions of category, distribution and selection do not apply (at least in the same way). In linguistic prosody, the head of a phrase is often assumed to be the most prominent element: for example, the head of an Intermediate Intonational Phrase can be considered to be the Nuclear Pitch Accented syllable (see Shattuck-Hufnagel and Turk 1996 for a review).
I will here follow Lerdahl and Jackendoff (1983: 108-109) in distinguishing between surface salience and structural importance. Instead of using the notion of salience or prominence, they define the head, i.e. the most important element of a time-span (rhythmic unit) to which the other pitch-events are subordinated, based on pitch stability and rhythmic criteria. Thus, the notion of head is based on the fact that all the pitch events of a piece are heard in a hierarchy of relative importance, as already assumed in the Schenkerian analysis of music (Schenker 1935). In other words, in a musical piece, we can distinguish between the core structure or skeleton and the elaboration subordinated to that core structure; this moreover applies at different levels, so that Lerdahl and Jackendoff (1983) note pitch reductions (or 'time-span reductions' in their terms) using trees (see tree in Figure 3 above): the higher the branch of a note is attached in the tree, the more essential the note is to the skeletal structure of the melody; the lower it is attached, the more ornamental the note is. At each hierarchical level, the notes forming the reduction are the heads of their rhythmic units. Lerdahl and Jackendoff (1983: 106) phrase this insight as the Reduction Hypothesis. I hypothesize that the notion of reduction is also relevant in dance as described in (19) below: the steps of a choreography are perceived as organized in a hierarchy of relative importance.

(19) *Reduction Hypothesis in dance*: the observer attempts to organize all the dance events of a choreography into a single coherent structure, such that they are perceived in a hierarchy of relative importance.

This is attested by the existence of dance marking and choreographies based on theme and variation.
Dance marking is a movement reduction strategy used by dancers when learning or rehearsing a choreography, which essentially involves a run-through of the dance-routine (see Warburton et al. 2013, a.o.); only the most important steps are marked by the dancer who using simplified versions of them or hand gestures: for instance, preparatory or transitional movements and ornamental movements are not necessarily marked. An example of ornamental movement in ballet is the *batterie* ('battery'), which consists of switching legs a number of times in the air while beating the calves together during a jump: the same jump can be executed without *batterie* without changing the structure of the dance; so just like a mordent in music, *batterie* seems to be simply ornamental (see examples of *batterie* in this excerpt from *Etude* by Harald Lander: http://www.youtube.com/watch?v=GGO2DmXto80&t=32m45s). More generally, movements performed by some body parts can be perceived as ornamental as compared to movements performed by other body parts, based on a hierarchy specific to the dance idiom: ballet is traditionally known to favor the movement of legs over other body parts like arms that can only feel secondary, or hips that are not supposed to move at all; conversely, belly dance favors the movement of hips over that of other body parts.
Just like in music, theme and variation is a form in which a basic movement theme is stated and then altered in various ways using different devices such as inversion, retrograde and transposition: movements subordinate to the basic movement such as turns or limb movements can be added, directions or orientations can be modified, some steps can be reversed…etc (for a toy example of theme and variation, see http://www.artsalive.ca/en/dan/make/toolbox/formstructure.asp). This is particularly relevant in folk dance: in Bulgarian dances for instance, some dancers improvise variations on basic steps, which can sometimes lead to competitions between dancers. Both dance marking and theme and variation are thus clear cases showing that a dance choreography can be reduced out, just like a musical piece.

This implies that in dance too, headedness related to the notion of reduction is relevant, and we can define the head as the most important element of a rhythmic unit, which remains in its reduced version (in Lerdahl and Jackendoff (1983), rhythmic units or time-spans are defined based on both grouping structure and metrical structure, see Section 4 for discussion about metrical structure in dance). Moreover, I assume that just like in music, both stability and rhythmic criteria determine headedness in dance.
Stability in music is defined based on relative degrees of consonance and dissonance in a tonal pitch space (see Lerdahl 2001a). If we equate tonal pitch space and physical space, we can similarly suppose that stability in dance is defined based on relative degrees of balance. Balance primarily depends on gravity (cf. Lasher 1981): a maximally balanced position is a position in which the dancer is completely stable in relation to gravity, such as the natural standing position or a lying position on the floor; an unbalanced position is a position in which the dancer is precariously balanced in relation to gravity, e.g. when one or both feet have lost contact with the ground or when the dancer balances on other unstable body parts (arms, head…). Instability correlates with increase of energy: unstable positions and steps require more energy from the dancer (against gravity) than stable ones; this is the case of all movements happening on the vertical axis (specifically

jumps or partner lifts). Regarding body parts, this means that any movement of bending or extending a body part increases instability: in short, the closer a movement is to a relaxed, natural position, the more stable it is.
In general, stability with respect to gravity requires a symmetrical configuration of the body, which may be why symmetry is perceived as a property of stability. But this holds in a more general and abstract way too: stability correlates with symmetry not just at the level of the body, but also at the level of the room; for instance, a position in the center of the scene is perceived as more stable than a position on the side of the scene. In general, the point of equilibrium of dances happening on a stage is the center of the scene: the closer to the center the movements are performed, the more stable they are perceived - thus the more important. This holds both for the steps of a single dancer, and for the simultaneous movements of several dancers. The latter is reflected in the traditional arrangement of dancers in ballet where the *corps de ballet* often stands in the back and sides as opposed to the principal dancer dancing in the center (e.g. in *Swan Lake* by Petipa/Noureev: http://www.youtube.com/watch?v=9rJoB7y6Ncs&t=47m15s). In short, just as in music, the more intrinsically consonant and the more closely related to the tonic a pitch event is, the more stable it is, in dance, the more intrinsically balanced and the closer to the center of the scenic space a dance event is, the more stable it is
Thus, stability based on the notions of symmetry and balance in relation to gravity (comparable to harmonic stability in music) is one of the conditions determining headedness. Another one is related to rhythmic criteria, which amounts to metrical stability in music. We can again transpose this to dance: in dances where the metrical structure is relevant (see discussion in Section 4), the head is preferably associated with metrical strength, which often corresponds to impulses of energy as is clear in ballroom dancing or folk dance (cf. Schlenker 2016 for the equivalent in walking).

In sum, headedness in dance is primarily characterized by stability, which comes in different types as summarized in (20). Not all notions of stability necessarily match and some can even be in conflict (e.g. balance vs. impulse of energy potentially creating loss of balance), which means that depending on the cases, one notion may prevail over another.

(20) *Headedness in dance*: the head of a group is the most *stable* element:
  a. most stable with respect to gravity (balanced and symmetrical body)
  b. most stable with respect to the scenic space (centered and symmetrical)
  c. most stable with respect to metrical strength (impulse of energy)

4. Other types of structure in dance

In the previous section, we have observed that a dance routine can be segmented into headed groups, and that this grouping structure is hierarchical. This makes dance similar to the other cognitive systems characterized by a grouping structure, including music: in fact, grouping structure is very broad in its application, concerning for instance visual perception of static and moving objects as well as auditory perception of e.g. prosody and music.

In this last section, the goal is to examine whether dance shares with music other types of structure that seem to be more specific to music, such as pitch structure based on pattern of tension and relaxation, and metrical structure. This should clarify the relation between dance and music perception in terms of cognitive systems (are they part of the same system that can be expressed in different modalities?) and in terms of their correspondence when happening simultaneously as is often the case, given that dance is most of the time accompanied by music. For space reasons, only basic ideas will be presented and a more thorough investigation is left for future work.

4.1. Prolongational reduction

Lerdahl and Jackendoff (1983) propose that another type of structure – called prolongational reduction - should be added to time-span reduction in order to capture the sense of continuity across group boundaries. While time-span reduction is based on the relative stability of pitch events within rhythmic units, prolongational reduction is based on relative stability of pitch events across rhythmic units, in terms of continuity and progression, tension and relaxation, closure or non-closure.

(21) *Prolongational hypothesis in music* (Jackendoff and Lerdahl 1983: 211, 213): intuitions about pitch-derived tension and relaxation in a piece can be expressed in terms of a strictly hierarchical segmentation of the piece into prolongational regions such that:

a. each region represents an overall tensing and relaxing in the progression from its beginning to its end;
b. tensings and relaxings internal to each region represent subordinate and nonoverlapping stages in the overall progression;
c. the choice of events that define prolongational regions is strongly influenced by the relative importance of events in the time-span reduction.

I hypothesize that the notions of tension and relaxation are also highly relevant in dance, based on the notions of stability and intentionality.

4.1.1 Stability

It can be assumed that any type of instability in dance creates tension, which is resolved by a return to stability. This applies to different types of stability, such as those mentioned in section 3.6. First, an unbalanced position with respect to gravity, which involves risk-taking, arouses tension in the observer. This concerns both movement in the vertical dimension (movements on tip toes or pointe shoes in ballet, jumps, partner lifts) and asymmetrical movement in the horizontal dimension (i.e. moving part of the body towards one side induces loss of balance). Conversely, when balance is regained, the tension decreases and a feeling of resolution ensues. Thus, we can distinguish between several phases in a dance, which are structured based on tension and relaxation due to an alternation of stability and instability: a unit is perceived as such when a series of steps progresses from relative stability, through relative instability and returns to relative stability (cf. Lasher 1981); just as in the case of prolongational regions in music, such a unit extends across rhythmic units (see excerpt 0:15-0:20 from *Don Quichotte* by

Noureev for steps progressing towards a *grand jeté*, very unstable ballet movement in which the dancer leaps into the air to perform a split: https://www.youtube.com/watch?v=RNn9h-kFXNw&t=0m15s).
The same holds for abstractly unbalanced configurations: the more unbalanced a set of movements is, the more tension is created. This is the case of asymmetrical movements with respect to the body or to the room. For instance, when a set of movements is performed with one side of the body, tension can be created, and then resolved once the same set of movements is performed with the other side of the body; or when the dance only happens in one side of the scenic space, there is a tension and an expectation that the other side of the space will be used too. The correlation between asymmetry and tension on the one hand and symmetry and resolution on the other hand also holds for paths and patterns that the dancer traces in the performance area: a set of steps tracing a symmetrical pattern creates a sequence of tension (when the pattern is not symmetrical yet) and relaxation (when the symmetrical pattern has been completed. This is for instance the case in the *Blue Bird* variation of *Sleeping Beauty*, in which the set of movements creates a symmetrical wing motif (see excerpt 3:20-4:15 for a real performance at https://www.youtube.com/watch?v=ZXGR3dAXr04&t=3m20s and video 2B at http://www.artsalive.ca/en/dan/make/toolbox/elements.asp for a schematized version): when the dancer begins the second diagonal (at 3:42), which starts making the pattern symmetrical, tension decreases, which is completely resolved once the dancer finishes the movement at the center of the room, perceived as the point of equilibrium. In fact, as soon as a pattern traced in the scenic space, such as a geometrical figure, is perceived as completed (cf. principe of closure in (18) in previous section), this corresponds to a point of repose. More generally, relaxation occurs every time the dancer returns to a neutral position (with respect to the body and/or to the room). Finally, abstractly unbalanced configurations can result from mismatch between dance and music, which will be discussed in Section 4.3.

4.1.2 Intentionality

Another property of dance can contribute to creating patterns of tension and relaxation, namely perceived intentionality. Heider and Simmel (1944) and following studies based on the same idea have shown that agency and intentions are easily attributed to animated objects: movement is often associated with intention. The effect is even stronger in dance where the moving entity is a human being. Most cases of human movement (say, doing the dishes or playing tennis) are goal-oriented and their structure is based on this property (cf. event structure, Zacks and Tversky 2001). As mentioned at the beginning, one of the properties distinguishing dance from other types of human movement is that it is not goal-oriented, but is movement for itself. This does not mean, however, that no intentionality is perceived: the observer does not perceive in the dancer an intention of achieving something or reaching a goal in relation with the external world, but an intention pertaining to the movement itself. And perceived intentionality creates expectation that arouses tension, which is resolved once the intention is fullfilled.
First, intention can be associated with progressions towards instability described above, given that unstable positions and movements require an increase of energy, i.e. tensing correlates with increase of energy and relaxing with decrease of energy. The observer easily infers that a movement requiring more energy than is natural is intentional (cf.

Schlenker 2016 for the same type of inferences in music). Units consisting of a progression of steps towards instability (tension) resolved with a progression towards stability can thus be perceived as a preparatory-completing motion unit (cf. Lasher 1981). The same holds for the movement of body parts: given that several parts of the human body (especially legs, arms or trunk) can be more or less bent and more or less stretched, contrasts between shapes that are shrinking or expanding can be used to create tension and resolution; for instance, a leg that is strechted out to its fullest length is often perceived as a culminating point in ballet.
Second, the eyegaze of the dancer is crucial to perceived intentionality. It can give rise to an expectation of the observer with respect to the direction of the movement. It can also suggest interactions, e.g. when a dancer moves closer to the audience or towards another dancer, and this perceived intention of interaction creates tension. This can be especially exploited in dances involving two dancers, such as ballroom dancing, where the succession of movements can be perceived as intentional and resulting from an interaction between the two dancers.
Intention can be perceived not only at the level of the dancer, but also at the level of the choreographer (cf. Schlenker 2016 for several levels of intentionality in music – just as writer/composer and narrator need to be distinguished in music or literature, I do not mean the real choreographer here, but the abstract entity to whom the dance as intentional product is attributed). The relative status of different movements can give a general structure to the choreography (cf. Martin and Pesovár 1961 for motif-morphology in Hungarian dances): for instance, some moves can be repeated so as to be perceived as recursive themes (for a example of recursive theme in ballet, see excerpts 23:56, 24:15, 26:30, 26:38, 26:55, 30:55, and 31:20 from *The Crystal Palace* by Balanchine in http://www.youtube.com/watch?v=bh5lkABh2ww&t=23m48s); other moves can be construed as contrasting with the main theme, and a final modification of the theme can lead to what can feel as a resolution of the dance. This corresponds to a more general notion of tension and relaxation at a larger scale of organization, namely at the level of the whole choreography. This is comparable to general structures of literary work such as novels or theater plays. In fact, dance and narration have easily been associated in narrative ballets such as *Sleeping Beauty*, *Swan Lake* or *The Nutcracker*.

In sum, another type of structure in dance results from patterns of tension and relaxation deriving from alternations between relative stability and instability, and from patterns of expectation and resolution based on perceived intentionality in the dancer and the choreographer. Note that such properties could be the basis of a semantics of dance, which is left for a future occasion.

4.2. Metrical structure in dance

Music is notoriously characterized by its metrical organization, which is essential to rhythm: according to Lerdahl and Jackendoff (1983), rhythmic organization is the product of both grouping and meter. The basic unit of metrical structure is a beat, a point in time usually associated with the onset of a note in the musical surface, and beats are combined into a metrical grid, a hierarchical pattern of beats of different relative strengths aligned with the musical surface (for an example, see Figure 2 above). Thus, the metrical structure of music is also hierarchical, just like its grouping structure and its pitch structure.

Does metrical structure also play a role in dance? In other words, is dance characterized by a hierarchical regularity of timing? Indeed, periodicity alone is not sufficient to postulate a metrical structure: as noted in Jackendoff and Lerdahl (2006), metrical grids require a differentiation between strong and weak beats, projected hierarchically. Thus, activities such as walking or breathing cannot be considered as having a metrical structure, althougth they involve temporal periodicities: they present no evidence for metrical grids extended beyond two levels. Jackendoff and Lerdahl (2006: 11) interestingly suggest that besides music and language (cf. stress grids), the only "promising candidate for metrical parallels with music is dance, where movement is coordinated with musical meter".

In fact, the question whether dance is intrinsically associated with a metrical structure is precisely complexified by the fact that it is most of the time accompanied with music (see section 1.4.), which has a metrical structure: does dance have an inherent meter or is the meter of music imposed to dance? The question arises all the more since psychological studies show, based on cases where the senses deliver conflicting information, that while vision dominates spatial processing, audition dominates temporal processing: for example, a repetitive sound presented simultaneously with a flickering light causes the rate of perceived visual flicker to shift toward the auditory flutter rate (e.g. Shipley 1964, a.o.). Furthermore, according to Guttman *et al.* (2005), this sensory specialization results in crossmodal encoding of unisensory input into the task-appropriate modality: they show that rhythm (temporal structure) portrayed solely by visual input receives automatic, obligatory encoding in the auditory domain.

This hypothesis of an obligatory cross-modal encoding of temporal structure implies that dance accompanied by music cannot have a metrical structure on its own, independent of the metrical structure of music: under this hypothesis, the association of music and dance has a single metrical structure, and given the auditory dominance over vision for temporal processing, the primary input of this metrical structure is the music. According to the modality-appropriateness hypothesis in psychology (Welch, 1999, a.o.), perception indeed gives precedence to the more appropriate sensory modality for the task at hand, namely the auditory modality for temporal processing. For instance, the metrical structure is not necessarily apparent in ballet movements, except in the correspondence with their grouping structures as will be discussed in the next subsection (see excerpt from Nikiya's death in *La Bayadère* by Rudolf Noureev: http://www.youtube.com/watch?v=FEdDKxmpSzY&t=0m40s) or in hardly rhythmical dance genres such as Japanese Noh, traditional Java dancing or Butoh for instance (e.g. http://www.youtube.com/watch?v=9ms7MGs2Nh8&t=0m40s). This does not mean, however, that dance cannot exhibit a metrical structure: although it is arguably *encoded* in the auditory domain, temporal structure can be *inferred* from visual stimuli. But this means that the metrical structure of dance has to be the same as that of the accompanying music.[14]

[14] From the perspective of the production, this is why when we dance, we tend to naturally synchronize with the music.

(22) *Crossmodal encoding hypothesis for meter*: a dance-music event (dance accompanied by music) has a single metrical structure: dance and music perceived simultaneously share a common representation of metrical structure.

Cases of metrical structures only inferred from dance can in principle occur in dance in silence. In general though, dance unaccompanied by music does not seem to be characterized by a metrical structure, but only by a grouping structure (see for instance *Trio A* by Yvonne Rainer http://www.youtube.com/watch?v=qZwj1NMEE-8&t=0m25s). As mentioned by Jackendoff and Lerdahl (2006), this also happens in some musical genres such as recitative and various kinds of chant, which demonstrates that grouping and meter can be dissociated; in fact, neuropsychological evidence for their independence has been provided based on cases of brain damage (Peretz 2001, a.o.). Nevertheless, the absence of metrical structure seems to be more pervasive in dance than in music. The auditory dominance over vision for temporal processing may explain why: we do not tend to assign a metrical structure to visual stimuli.[15] The case of dance in the Deaf community interestingly supports this idea (cf. *The Wild Zappers* with National Deaf Dance Theater https://www.youtube.com/watch?v=DlCwb9GJ6xk): because the auditory modality is not relevant, the visual modality is instead used for temporal processing, and the metrical structure of the dance is thus highly marked. Note that in this respect, the study of the rhythmic properties of sign languages as compared to spoken languages could be informative (cf. Allen, Wilbur and Schick, 1991, a.o.).

Thus, dance can have a metrical structure even if the visual modality is usually not the most appropriate modality for expressing it. What are its principles? I will only provide some preliminary ideas here, but note that a detailed investigation of dance accompanied by music with clear metrical structure could be an easy way to address this question, given the crossmodal encoding hypothesis.

First, it seems that beats are often associated with vertical movements towards the ground. In particular, regular foot steps often mark the pulsation, as can be observed in ballroom dances and folk dances. More precisely, movements involving a transfer of weight from one foot to the other should be distinguished from vertical movements affecting a single foot, such as hops (cf. Singer 1974 for Macedonian dance). As can be clearly observed in African dances (e.g. traditional setswana dance in Botswana: http://www.youtube.com/watch?v=xf1fgCe0Aig&t=0m17s), weight shifts are associated with stronger beats than foot movements without any weight transfer, thus yielding two hierarchical levels of metrical structure.

The distinction between different metrical levels can also be expressed in dance by movements of different body parts. Studies on music-induced movement (Toiviainen *et al.* 2010, Su 2016, a.o.) show that body parts are assigned specific roles corresponding to different hierarchies of metrical structure. For instance, vertical movement such as trunk bouncing is often associated with lower-level periodicities, while limb movement and mediolateral movements of arms are often found to be frequently synchronized with higher (distinct) hierarchical levels.

Ballroom and folk dances show that higher-level periodicities can also be expressed using grouping principles such as symmetry, parallelism/repetition, closure, or change of

[15] Interestingly, tap dance provides its own percussion in the auditory modality.

various parameters like direction. The correspondence between grouping and metrical structure will be discussed in the next subsection.
Thus, at least three levels of metrical structure can be expressed in dance using movements of different body parts and weight shift, with vertical movement (of the trunk or legs) usually associated with lower metrical levels. But this does not mean that all the metrical levels of the accompanying music must be expressed. In fact, this is a factor of variation in the adaptation of the same music to different choreographies. For instance, the metrical grid of the first eight bars of the *Dance of the Young Maidens* from the *Rite of Spring* by Stravinsky (http://www.youtube.com/watch?v=Ceglu9msRbo&t=3m35s) is reflected in different ways in the different choreographic adaptations: in Nijinsky's (1913) choreography (http://www.youtube.com/watch?v=dVPIkvHKRB8&t=3m59s), the eight note level is marked by small jumps and the half note level by repetition and return to the initial position (and the accents are indicated by arm movements); in Béjart's (1970) choreography (http://www.youtube.com/watch?v=XedawBHB-uc&t=3m17s), only the quarter note level is represented; as for Pina Bausch's (1975) choreography, (http://www.youtube.com/watch?v=nd_ZCuqYdVE&t=4m12s), changes of position indicate the quarter note level, and repetitions and returns to the initial position signal the full note level. Conversely, the metrical structure of the same choreography can be adapted to different musics, and this can be done in different ways by matching different hierarchical levels of the music. For instance, steps-hops in Gallotta's choreography Ulysse are perceived in ternary timing in the 1993 version *Ulysse, re-creation* on a music by Torgue and Houppin (see excerpt 0:10-0:16 at http://www.numeridanse.tv/en/video/213_ulysse), but in binary timing in the 2007 version *Cher Ulysse* on a music by Strigall (see excerpt 8:56-9:02 at http://www.numeridanse.tv/en/video/296_cher-ulysse).

Many aspects of the metrical structure of dance remain to be investigated, but these preliminary remarks show that dance can exhibit a metrical structure. This is not obligatory though: the metrical of a dance-music event is preferably inferred from the music, given that the auditory modality is more appropriate for temporal processing. This implies that music often has to be taken into account for inferring the metrical structure of a dance event accompanied by music: even if the structure of dance can be investigated independently, a full understanding of a dance-music event can only be obtained if both the structures of the music and the dance are examined both independently and in relation to each other. In the next and last section, we turn to a brief examination of the relation between music and dance with respect to grouping structure; the study of the correspondence between the pitch structures of dance and music is left for a future occasion.

4.3 Correspondence between dance and music

In Section 3, we have shown that local and global principles of grouping apply in both dance and music, forming multiple levels of organization in a sequence of movements or in a sequence of notes. This raises the following question: in a dance-music event, how do musical groups relate to dance groups? I here hypothesize that there is a general preference for harmonizing the grouping structures of dance and music: observers tend to match the boundaries of the musical groups with the boundaries of the dance groups if possible. Even more, they prefer to synchronize group boundaries of the same hierarchical level. A perfect match is achieved if each musical group of a certain level exactly matches each dance group of the same level, as captured by the grouping preference rule below.

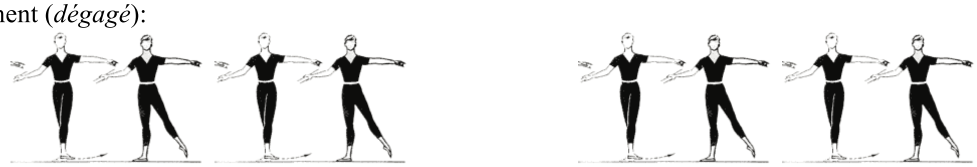
(23) *GPR 14* (correspondence between dance and music grouping): in a dance-music event, the grouping structure of the dance and the grouping structure of the music coincide.

This rule is often obeyed in folk dances and in cases in which the forms of dance and music were created for each other (e.g. waltz, tango, salsa). This is also intentionally aimed at by some choreographers such as Balanchine (according to him, "dancing is music made visible"): in his creations, the dance movement parallels the structure of the music, that is, movement phrases are in synchrony with musical phrases, which results in a perfect consonance of visual and aural patterns. Also, note that music accompanists in dance classes are generally trained so as to know how to match their music with the movements to be learned (cf. Wong 2011).
The correspondence between music and dance can furthermore resolve cases of ambiguity: if the musical structure is ambiguous between different interpretations, the position of the movement phrases on the music can contribute to disambiguating it. For instance, the first eight bars of the *Dance of the Young Maidens* mentioned above (http://www.youtube.com/watch?v=Ceglu9msRbo&t=3m35s) have in principle a multiply ambiguous structure since the same chord is repeated the whole time (the only variation is the placement of the accents), which can yield several possible groupings based on the global grouping rule of repetition (GPR 11); Pina Bausch's choreography (http://www.youtube.com/watch?v=nd_ZCuqYdVE&t=4m12s) disambiguates it in showing four dance groups based on the repetition of the same sequence of movements four times. Conversely, the accompanying music can lead the observer to choose one grouping interpretation of the dance over another. For example, in the excerpt 1:01-1:21 (https://www.youtube.com/watch?v=Cv9Yms5Q3Gg&t=1m1s) from *Grand Pas Classique*, the four identical sequences of movement could in principle be grouped in different ways at a higher level based on the global rule of repetition (GPR 11); the accompanying music with two repeated phrases disambiguates the dance by segmenting it into two higher-level groups.

Even if there is a cognitive preference for matching the structure of dance with that of the accompanying music, this does not mean that mismatch does not happen or is always dispreferred. In fact, cases of mismatch produce powerful artistic effects. This has been exploited in extreme ways by choreographers like Cunningham who denies any rapport between dance and music, as mentioned in Section 1.4 (see *Second Hand* for instance, choreography by Merce Cunningham and music by John Cage http://www.youtube.com/watch?v=-FwiMlDQ7rI&t=0m15s). But even if the general preference for match between music and dance grouping is respected, cases of occasional mismatch within a dance can be used as a way to create patterns of tension and resolution, which add complexity to the general structure of the dance-music event. For instance, in excerpt 4:20-4:35 of the dance of the Wilis from the second act of *Giselle* (http://www.youtube.com/watch?v=X2tEkyRIJbY&t=4m20s), we can observe that the *arabesque* (posture in which the body is supported on one leg, with the other leg is extended horizontally backward) at 4:31 does not correspond to any group in the music, and moreover, its lyrical and fluid quality is in conflict with the strong rhythmic and jerky quality of the music. Such conflicts should also be examined for understanding the semantics of a dance-music event.

Furthermore, Lerdahl and Jackendoff (1983) argue that the interaction between the grouping and metrical structures of music (that must be kept separate, because on the one hand, groups do not receive metrical accents, and on the other hand, beats do not possess inherent grouping) determine its rhythmical properties. For instance, upbeats can be distinguished from afterbeats depending on the relative position of the closest grouping boundary (Lerdahl and Jackendoff 1983: 28). Moreover, grouping and metrical structures can either be in phase or out of phase in varying degrees. In the former case, a group extends between beats at the same metrical level and the first beat of the group is the strongest beat, so that the span produced by the group coincides with a metrical time-span. In the latter case, the grouping boundaries cut across the periodicity of the metrical grid; this is for instance the case if a group begins on a beat weaker than the strongest beat in the group (i.e. if it begins on an upbeat).
Similarly, we can assume that the rhythmic organization of the dance is determined by the interaction between grouping and meter. First, an equivalent of the distinction between upbeats and afterbeats in dance can be found in ballet in the distinction between movements performed "the accent out" or "the accent in". This is for instance the case of *battements tendus* (alternating side-to-side movement of the working, i.e. non-supporting, leg, where the extended foot never leaves the floor) as illustrated in Figure 34 (as in Figure 2, each vertical column of x's represents a beat, and the height of the column indicates the relative strength of the beat). When the dancer moves his leg out on the upbeat, he reaches the "in" position on the downbeat of the music (accent out); when he moves his leg out on the downbeat, he reaches the "in" position on the upbeat of the music (accent in). In other words, "accent out" corresponds to the upbeat in music, because the movement performed on the weak beat is grouped with the movement performed on the strong beat.

movement (*dégagé*):



```
meter:    x     x        x     x            x     x     x     x
          x              x                        x           x
group:  ------||--------------------||---------    -------||--------------------||-----------
                  accent out                                  accent in
```

Figure 34. Accents "in" and "out" in ballet
(image of battement tendu from http://www.balletto.net/trucchi.php?pagina=metodologia10.html)

Furthermore, the grouping structure of dance and the metrical structure of the dance-music event can also be in phase or out of phase. But just as in the case of grouping, I hypothesize that there is a general preference for matching them. That is, movement phrases are usually preferred to extend between beats at the same metrical level, and the beginning of the movement group starts on the strongest beat, so that the span of the dance group coincides with a metrical time-span. This is clearly the case in Béjart's (1960) choreography on Ravel's *Bolero* (e.g. http://www.youtube.com/watch?v=rybdgpCWk5I&t=5m50s). That's also why the music often has to be adapted to dance groups. Different types of dance use different types of phrases as a basis: for instance, while a traditional ballet phrase has eight counts and is always regular, modern dance often uses irregular meters (5/4, 7/4) and changing meters; ballroom dances and folk dances are also characterized by specific meters (e.g. 4/4 for the Foxtrot, see Myers 1979). Music accompanists take this into account (cf. Wong 2011).

(24) *GPR 15* (correspondence between dance grouping and meter): in a dance-music event, the metrical structure and the grouping structure of the dance coincide.

But just as in the case of the interaction between the grouping structures of music and dance, this does not mean that the dance grouping and meter are always in phase: discrepancy between them can create interesting effects. In fact, the example cited above (the excerpt from *Giselle*) as a case of mismatch between music and dance grouping is also a case of mismatch between dance grouping and meter.

In sum, the rhythmical structure of dance is the result of a twofold interaction between the dance grouping structure and the music grouping on the one hand, and between the dance grouping and the metrical structure of the dance-music event on the other hand. In cases of tight matches, the dance-music event is perceived as highly harmonious, while cases of mismatch give rise to the same kind of rhythmical effects as syncopation in music. A more detailed investigation would be required to further understand all the different principles of music and dance interaction and their effects. I leave it for future work.

Conclusion

Adopting the same kind of formal methods as those adopted in linguistic theory to questions of dance cognition thus promises to be fruitful: a grammar of dance perception can be built by systematically examining the organizational principles of dance movement representation. In this paper, I have mainly focused on principles that determine groups in dance. The other types of organizational principles, such as those based on meter and tension/relaxation, which I have only briefly discussed, would be worth exploring in more depth in the future.
The construction of a dance grammar should hopefully shed further light on the relation between different cognitive systems, in particular on that between dance, music and language. This preliminary investigation has already confirmed that grouping principles as such seem to be part of a general cognitive capacity shared by all these systems and

others such as static visual perception, even if the parameters responsible for them are modality-specific. Metrical structure, however, seems to be specific to dance and music; I have moreover hypothesized that it is preferably inferred from the auditory modality (the music), but can be reinforced by the visual modality (the dance), so that simultaneous dance and music share the same metrical structure. This could suggest that dance and music perception share a cognitive module: just as sign and spoken languages share the same cognitive system dedicated to language although they are expressed in different modalities, there may be a narrow cognitive capacity that is common to dance and music. A precise comparison of pitch structure and its equivalent in dance could also shed more light on this issue.

Such a specific relation between dance and music would also explain how dance is different from movement in general, or even from other types of human movement. Certainly, certain principles of organization are shared by all types of movement, which all involve the space and the time dimensions. An even broader set of principles is probably common to dance and other types of human movement, in which the entity changing position with respect to time is crucially a human being with specific anatomical constraints and psychology (e.g. intentionality). But principles specific to the dance/music module would ultimately make dance different from them.

In sum, further steps should be taken towards the elaboration of a generative theory of dance cognition as a way to further explore human cognition through a better understanding of one of its cognitive systems and its comparison with others.

References

Allen, George D., Ronnie B. Wilbur, and Brenda B. Schick, 1991: "Aspects of rhythm in ASL." *Sign Language Studies* 72.1: 297-320.

Bailyn, John Frederick, 2015: "Language, Music, Fire, and Chess: Remarks on Music Evolution and Acquisition." *Language, Music, and Computing*. Springer International Publishing. 27-44.

Balanchine, G.: *By George Balanchine.* Edited by T. W. Schoff. New York: San Marco, 1984. Collection of short quotations from Balanchine's public statements.

Bernstein, L., 1976: *The Unanswered Question: Six Talks at Harvard*. Harvard University Press.

Berthoz, A., 2001: *The Brain's Sense of Movement*. Harvard University Press.

Brentari, Diane, 1998: *A prosodic model of sign language phonology*. MIT Press.

Chomsky, N., 1981: *Lectures on Government and Binding*. *Dordrecht: Foris*.

Eitan, Z., and R. Y. Granot, 2006: How music moves. *Music Perception* 23, 3:221-247.

Emmorey, K., 2001: *Language, cognition, and the brain: Insights from sign language research*. Psychology Press.

Fodor, Jerry A, 1983: *The modularity of mind: An essay on faculty psychology*. MIT press.

Foster, S. L., 2008: “Movement’s Contagion: The Kinesthetic Impact of Performance”. *The Cambridge Companion to Performance Studies*: 46-59.

Guttman, S. E., Gilroy, L. A., & R. Blake, 2005: Hearing what the eyes see auditory encoding of visual temporal sequences. *Psychological science*, *16*(3), 228-235.

Hagendoorn, I. G., 2004: “Some Speculative Hypotheses about the Nature and Perception of Dance and Choreography”. *Journal of Consciousness Studies* 11 (3/4), 79-110.

Heider, F., and Simmel, M., 1944: An experimental study of apparent behavior. *American Journal of Psychology*, 57, 243-259.

Van der Hulst, Harry, 1993. "Units in the analysis of signs." *Phonology* 10.02: 209-241.

Jackendoff, R., 2009: “Parallels and Non-Parallels between Language and Music”. *Music Perception* 26, 195-204.

Jackendoff, R., & F. Lerdahl, 2006: “The capacity for music: What is it, and what’s special about it?”. *Cognition*, *100*(1), 33-72.

Kaeppler, A., 1972: “Method and Theory in Analyzing Dance Structure with an Analysis of Tongan

Dance”. *Ethnomusicology* 16 (2): 173-217.
Katz, J. & D. Pesetsky, 2011: “The Identity Thesis for Language and Music”. lingBuzz/000959.
von Laban, R., 1966: *The Language of Movement; A Guide Book to Choreutics*. Boston: Plays.
Lasher, M. D., 1981: “The Cognitive Representation of an Event Involving Human Motion”. *Cognitive Psychology* 13, 391-406.
Lerdahl, F. and R. Jackendoff, 1983: *A Generative Theory of Tonal Music*. MIT press.
Lerdahl, Fred, 2001a: *Tonal pitch space*. Oxford University Press.
Lerdahl, Fred, 2001b: "The sounds of poetry viewed as music." *Annals of the New York Academy of Sciences* 930.1: 337-354.
Lerdahl, Fred, 2013: "Musical syntax and its relation to linguistic syntax." *Language, Music and the Brain*: 257-272.
Longstaff, J.S., 1996: *Cognitive Structures of Kinesthetic Space; Reevaluating Rudolf Laban’s Choreutics in the Context of Spatial Cognition and Motor Control*. Ph.D. Thesis. London: City University, Laban Centre. (HTML Edition)
Martin, G. & E. Pesovar, 1961: “A Structural Analysis of the Hungarian Folk Dance”. *Acta Ethnographica* 10:1-40.
Myers, Edward, 1979: "A Phase-Structural Analysis of the Foxtrot, with Transformational Rules." *Journal for the Anthropological Study of Human Movement* 1.4: 246-68.
Patel, A. D., 2008: *Music, Language, and the Brain.* NY: Oxford University Press.
Peretz, I. (2001). Music perception and recognition. In B. Rapp (Ed.), The handbook of cognitive neuropsychology (pp. 519–540). Philadelphia: Psychology Press.
Rebuschat, P., M. Rohrmeier, J. A. Hawkins, I. Cross (eds), 2011: *Language and Music as Cognitive Systems*. Oxford University Press.
Sandler, Wendy. (2003). Sign language: Phonology. In W. Frawley (Ed.), *The Oxford international encyclopedia of linguistics, second edition, volume 4* (pp. 57-60). Oxford : Oxford University Press.
Sandler, W. & D. Lillo-Martin 2006: *Sign Language and Linguistic Universals*. Cambridge, UK: Cambridge University Press.
Schenker, Heinrich, 1935: “Der Freie Satz”. Vienna: Universal edition *Trans. and ed. E. Oster:* "Free Composition." *New York: Longman, 1979).*
Shipley, T., 1964: Auditory flutter-driving of visual flicker. *Science* 145:1328–1330.
Schlenker, P., 2014: “Iconic Features”. *Natural Language Semantics* 22(4): 299-356.
Schlenker, P., 2016: Prolegomena to Music Semantics. Manuscript. lingbuzz/002925.
Selkirk, Elisabeth O, 1986: *Phonology and syntax: the relationship between sound and structure*. MIT press.
Shattuck-Hufnagel, Stefanie, and Alice E. Turk, 1996. "A prosody tutorial for investigators of auditory sentence processing." *Journal of psycholinguistic research* 25.2: 193-247.
Singer, A., 1974: “The Metrical Structure of Macedonian dance”. *Ethnomusicology* 18(3): 379-404.
Stokoe, William C, 1960: "Sign language structure (Studies in Linguistics." *Occasional paper* 8 (1960).
Stokoe, William C., Dorothy C. Casterline, and Carl G. Croneberg, 1976: *A dictionary of American Sign Language on linguistic principles*. Linstok Press.
Su, Yi-Huang, 2016: "Visual tuning and metrical perception of realistic point-light dance movements." *Scientific reports* 6.
Toiviainen, G. Luck, & M. R. Thompson, 2010: “Embodied Meter: Hierarchical Eigenmodes in Music-Induced Movement”. *Music Perception* 28 (1), 59–70.
Wagner, Michael, and Duane G. Watson, 2010: "Experimental and theoretical advances in prosody: A review." *Language and cognitive processes* 25.7-9: 905-945.
Warburton E. C., M. Wilson, M. Lynch & S. Cuykendall, 2013: “The Cognitive Benefits of Movement Reduction: Evidence From Dance Marking”. *Psychological Science* 24(9), 1732–1739.
Welch, RB, 1999: Meaning, attention, and the “unity assumption” in the intersensory bias of spatial and temporal perceptions. In: Aschersleben, G.; Bachmann, T.; Musseler, J., editors. Cognitive contributions to the perception of spatial and temporal events. Elsevier; Amsterdam, 371-387.
Wong, Y. S., 2011: *The Art of Accompanying Classical Ballet Technique Classes*. Doctor of Musical Arts thesis, University of Iowa.
Zacks, J. M., & B. Tversky, 2001: Event structure in perception and conception. *Psychological bulletin*, *127*(1), 3.