Musical Social Entrainment

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Abstract
Over the last decade, the concept of entrainment—emerging from the fields of physics and biology—has grown as a tool for investigating rhythmic adjustments among musicians, and between different groups of musicians. When combined with methods of audio data analysis, this approach has benefits for the assessment of musical behavior, previously limited to largely descriptive ethnomusicalological research based on ethnographic data collected through field study. However, musical behavior is not only biophysically determined, but also a highly social activity. Therefore, this article focuses on “social entrainment”—a concept coined by the social scientists Joseph E. McGrath and Janice R. Kelly in 1986 which recently has been taken up in music research. Relating this concept to certain approaches in relevant current empirical studies on interpersonal coordination, the authors develop their own categories of social behavior, which are broader than those of social entrainment but can accordingly be applied to the social entrainment that may occur in musical practices. These categories range from basic behaviors that do not involve social cognition but are meaningful to interacting individuals and groups, to high-order social behaviors that require collective intentionality and can lead to sophisticated interaction involving music-specific phenomena such as a “groove.” Consequently, a concept of entrainment which goes beyond both an adaptation of the established concept of physical and biological entrainment and McGrath and Kelly’s original concept of social entrainment is proposed: “musical social entrainment.” The authors use this term to refer to intra-individual, inter-individual, intra-group, and inter-group entrainment to exogenous musical rhythms—including the rhythms of other musically acting individuals and groups—embedded in a social context and contributing to sociality. Finally, reviewing selected studies relevant to musical social entrainment, the authors discuss problems and open questions concerning music-related entrainment research, and potential contributions in the future of entrainment studies in general.

Keywords
Group entrainment, inter-individual entrainment, intra-individual entrainment, musical entrainment, social behavior, social entrainment

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1. Introduction
Since the publication of “In time with the music: the concept of entrainment and its significance for ethnomusicology” in 2005 by Martin Clayton, Rebecca Sager, and Udo Will, empirical studies on entrainment have increased in the field of music research, especially regarding musical performance and musical practices.1 Coining the terms “inter-individual entrainment” and “inter-group entrainment,” Clayton, Sager, and Will (2005) adopt the concept of entrainment introduced through physics and biology to emphasize the rhythmic adjustment2 of oscillating objects that do not have the same oscillation3 period. In addition, the concept of inter-individual and inter-group entrainment encourages the study of social interaction in musical practices, especially as observed where music is shaped by two or more persons together. However, it is likely that rhythmic adjustments on an inter-individual level also occur in a more basal form of social behavior not involving social interaction.
To further develop this discussion, it is necessary to examine what precisely is meant by “social” in the term “social entrainment,” and to what extent the inter-individual or inter-group entrainment involved in a musical practice can serve a social interaction. In particular, because the growing number of music researchers investigating entrainment tend to work from the physical and biological concept, it must be taken into account that social behavior related to the process of shaping music collectively cannot be reduced to physical and biological parameters; to avoid miscommunication, the concept of social entrainment must be elaborated on and developed further. Therefore, the current article elaborates social entrainment, a concept adapted from, yet going beyond, the physical and biological concept of entrainment.

Moreover, the process of entrainment that takes place in music-making and music perception deserves more thorough discussion since it embraces basal processes that do not involve a social cognition (such as musical interaction taking place between infant and caregiver), as well as the processes that underlie high-order musical interaction based on collective intentionality (such as ensemble playing and establishing/maintaining phenomena like syncopation or laid-back). The process concerns not only inter-individual and inter-group entrainment, but also the neural entrainment that occurs while listening to musical sounds. We attempt to subsume these processes under the term “musical social entrainment,” which will prove to be partially similar but not equal to the existing terms “musical entrainment” (Clayton, Sager, & Will, 2005) and “social entrainment” (Clayton et al., 2005; Phillips-Silver, Aktipis, & Kelly, 2010).

We also introduce key concepts and necessary conditions of entrainment that have been developed in the disciplines of physics and biology but prove relevant to the concept of social entrainment as well (section 2.1). We then describe the categories of entrainment that are used in music research: self-entrainment and social entrainment (section 2.2). The concept of social entrainment is discussed in more detail, taking Joseph E. McGrath and Janice R. Kelly’s model of social entrainment into account (section 2.3). This discussion paves the way for a specific analysis of social entrainment, where we elaborate on collective intentionality (such as ensemble playing and establishing/maintaining phenomena like syncopation or laid-back). The process concerns not only inter-individual and inter-group entrainment, but also the neural entrainment that occurs while listening to musical sounds. We attempt to subsume these processes under the term “musical social entrainment,” which will prove to be partially similar but not equal to the existing terms “musical entrainment” (Clayton, Sager, & Will, 2005) and “social entrainment” (Clayton et al., 2005; Phillips-Silver, Aktipis, & Kelly, 2010).

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### 2. Social entrainment from biophysical entrainment?

The term “social entrainment” was coined in 1986 by Joseph E. McGrath and Janice R. Kelly, adapting the term “entrainment” developed in biology, which comes from the Middle French “entraîner” (“to draw,” “to drag,” Phillips-Silver & Keller, 2012) and refers to a process closely related to or sometimes synonymous with synchronization.4 McGrath and Kelly used this term to describe the interaction of human social rhythms, including interaction between two or more individuals and that between multiple rhythmic processes within one individual. According to McGrath and Kelly (1986), human “endogenous rhythms—temperature, cardiovascular, excretory, activational—[…] are often entrained to exogenous rhythms in the human’s environment” (McGrath & Kelly, 1986, p. 46 f.). This kind of entrainment to human exogenous rhythms is regarded as “socio-psychological” (McGrath & Kelly, 1986, p. 47) rather than “a biological matter” (McGrath & Kelly, 1986). The expression “human social rhythms” refers to those aspects of human behavior that have cyclic qualities, such as sleep-wake cycle, body temperature cycle or menstrual cycle: “Social entrainment refers to all those cycles of behavior, at the individual, group, or organizational level, that are captured and modified by one another or by an external pacer” (Kelly, 2010, p. 785). To what extent can such interactions among human social rhythms be described as social entrainment? What exactly is meant by “entrainment,” both alone and as modified by “social?”

McGrath and Kelly start from human biological rhythms to describe the interaction of human social rhythms, and use key concepts and necessary conditions related to entrainment in their discussion. We first discuss those concepts and conditions, then attempt to elaborate on the meaning of “social” in “social entrainment.”

#### 2.1 Definition and necessary conditions of entrainment

The Dutch physicist Christiana Huygens is credited with the discovery of the phenomenon of synchronization in 1665, which he described as “the sympathy of the clocks.”5 The terms “synchronization” and “entrainment” have therefore been used first in physics and biology, and later in other research fields, to refer to the same or closely related processes. Based on the groundwork of Henri Poincaré Les méthodes nouvelles de la mécanique céleste (1892, 1893, 1894) and other mathematicians and physicists, around the 1960s biologists focused their research on synchronization concerning biological systems. In 1965, Jürgen Aschoff published an article about circadian rhythms in human
beings—those rhythms that last about 24 hours (from Latin *circa*, about, and *die*, day). He conceived of human beings as self-sustained oscillators that have their own frequency, whose endogenous rhythms “synchronize with” or entrain to)—but are not imposed by—the Earth’s rotation period (Aschoff, 1965, p. 1427). In 1968, John Buck and Elisabeth Buck formulated a similar hypothesis in their article “Mechanism of rhythmic synchronous flashing of fireflies.” They suggested that the process of synchronization is based on endogenous rhythms, rather than on mutual responses to other individuals (Buck & Buck, 1968). More recently, applied mathematician Steven Strogatz analyzed the phenomenon of synchronization from the perspective of nonlinear dynamics and complex systems in a comprehensive and popular monograph (Strogatz, 2004). He pointed out the pervasiveness of the phenomenon using biological examples such as synchronous fireflies, brain waves, and circadian rhythms and examples derived from quantum mechanics and chaotic systems.

An influential monograph published in 2001 by Arkady Pikovsky, Michael Rosenblum, and Jürgen Kurths, *Synchronization: A universal concept in nonlinear sciences*, suggests a definition of synchronization in physics as “an adjustment of rhythms of oscillating objects due to their weak interaction” (Pikovsky, Rosenblum, & Kurths, 2001, p. 8). The authors used “entrainment” as a synonym for “locking” (Pikovsky et al., 2001, p. 23), which refers to two or more oscillators mutually locking in with one another or one oscillator unidirectionally locking in with an external force. Pikovsky, Rosenblum, and Kurths (2001, p. 15) specify that synchronization/entrainment requires the presence of autonomous oscillators, whereas resonance takes place when one or more of the oscillators involved has no rhythm of its own, that is to say, it is not an autonomous system.

This definition was taken up by Martin Clayton, Rebecca Sager, and Udo Will in their seminal article “In time with the music: the concept of entrainment and its significance for ethnomusicology” (2005) and applied for musical-rhythmic processes. Clayton et al. defined entrainment as “[... a process whereby two rhythmic processes interact with each other in such a way that they adjust towards and eventually ‘lock in’ to a common phase and/or periodicity” (Clayton et al., 2005, p. 5 f.). Based on both publications, four necessary conditions that occur in all instances of entrainment can be summarized as follows:

**Autonomous oscillator(s),** interacting either mutually with another/other oscillator/s, or unidirectionally with an external force. “Autonomous” means that the oscillator has an internal source of power which enables it to oscillate with its natural frequency, regardless of interaction; the oscillator is self-sustained. The concept of unidirectionality can be contextualized within the categories of symmetry and asymmetry. If entrainment is symmetrical, each oscillator influences the other/s equally. If there is any deviation from that symmetry, entrainment is asymmetrical, and the influences exerted by the oscillators on one another are not equally strong. Unidirectional entrainment is the most extreme case of asymmetrical entrainment: one oscillator influences the other/s but is not in turn influenced by it/them, that is to say, it is without any mutuality. The case of unidirectional entrainment of an oscillator with an external force is described by Pikovsky et al. 2001 but not by Clayton et al. 2005; a further, specific approach is that of the mechanical engineers Leonid I. Manevitch and Oleg V. Gendelman (2011), who narrow the meaning of “entrainment” only to the case in which an “external force imposes its frequency on the oscillator” (Manevitch & Gendelman, 2011, p. 72). They conceive of “entrainment” solely as a unidirectional process.

**At least weak interaction (or coupling strength)** between the rhythm of an autonomous oscillator and the rhythm of an external force or of another/other autonomous oscillator/s (Clayton et al., 2005, p. 6; Pikovsky et al., 2001, p. 10 ff.). According to Pikovsky et al. (2001, p. 11), coupling strength “describes how weak (or how strong) the interaction is.” The terms “interaction” and “coupling strength” are directly proportional but are not perfect synonyms. For instance, if two clocks are suspended from the same wooden beam but are switched off, they are coupled but do not interact. The strength of the interaction may vary: if the oscillators are weakly coupled, they return to their synchronous state slowly; if they are strongly coupled, they return to their synchronous state more quickly. If detuning is large, the coupling has to be sufficiently strong in order to compensate for it. If there is no coupling at all, there is no interaction—and without interaction, a disturbed synchronous system is not able to return to synchrony. A rigid coupling such as a beam results in the oscillators acting like a single system and not autonomously. All cases in between the two extremes (no coupling and rigid coupling) are considered *at least* weak interaction (i.e., there is some degree of interaction), and in this condition the oscillators are able to adjust to each other. Pikovsky et al. conceive of all synchronous-looking states, including random configurations, as “seemingly synchronous[]” (Pikovsky et al., 2001, p. 17). In Pikovskian terms, it is possible to test from a bottom-up perspective whether a seemingly synchronous state has been initiated by interaction or by chance.
Stable phase relationship: the phase relationship has to be constant. However, the rhythmic processes do not have to lock in a one-to-one ratio. An appropriate method to determine such a constant relationship is the calculation of the relative phase (Kelso, 1995). Relative phase is the difference between two variables (e.g., the onsets of two musicians) with respect to the period of one of them. For example, given two series of acoustic signals (series A and series B), the relative phase ($\Phi$) is calculated by dividing 360 degrees (the period of oscillation) by the period of A (duration between two successive beats of series A) and multiplying this result by the latency of B (point in time of occurrence of series B):

Relative phase ($\Phi$) = \((360: \text{period A}) \times \text{latency B}\)  

The calculation of the relative phase can be used to plot a graphic showing whether the phase relationship between two series of acoustic signals is stable or not. Furthermore, this calculation allows us to observe the process that leads to synchrony, that is, the process of rhythms that adjust to each other until they reach a constant phase difference—which we call “synchronization” (noting that “synchronisation” is different from “synchrony,” which refers to correlation of two or more events).

Disposition of an entrained system to reassert stability after a perturbation. According to Pikovsky et al. (2001), an entrained or synchronized system has the behavioral disposition to reassert its stability after a perturbation. Clayton et al. conceive of perturbation as a viable empirical method for determining whether the reassertion of the entrained system’s stability is based on interaction: “In order to identify entrainment one needs to examine perturbations or transitions of the synchronization process; only if synchronization is re-established after these disturbances […] does it seem justified to describe the interaction between the oscillators as entrainment” (Clayton et al., 2005, p. 48).

The assertion that entrainment can be identified only when synchronization is re-established after a perturbation has led to a misunderstanding. In their observational study taking up Clayton et al.’s articles, Andrew Geeves, McIlwain, and Sutton (2014) write that “entrainment hinges on the notion of disturbance” (Geeves, McIlwain, & Sutton, 2014, p. 1). This claim, however, is not underpinned by thorough discussion or robust method. It even contradicts Clayton et al.’s position, according to which reassertion—rather than perturbation—is the necessary condition: “In order to demonstrate that two rhythms are entrained, it is necessary to show that when autonomous rhythmic processes are coupled, (1) the phase relationship between them is stable, and (2) this stabilization is able to reassert itself following a perturbation” (Clayton, 2013, p. 21); “Stabilisation of this phase relationship (in particular following a disturbance) is taken as strong evidence for entrainment” (Alborno et al., 2015, section 2).

### 2.2 Concepts of self-entrainment and social entrainment in music research

Clayton et al. distinguish between self-, inter-individual and inter-group entrainment (Clayton et al., 2005; Clayton, 2012). Self-entrainment (Clayton et al., 2005, p. 14), also called “intra-individual” entrainment (Clayton, 2012, p. 51), is the result of coordination between two or more oscillators within an individual. By contrast, inter-individual and inter-group entrainment (Clayton, 2012)—which Clayton et al. (2005, p. 7) do not explicitly distinguish from social entrainment—occur when two or more individuals and groups, respectively, interact and adjust their rhythms to one another. In these cases, the rhythmic behaviors of individuals and groups participating in the interaction seem to be regarded as oscillations. According to scholars’ research perspectives, the focus typically is on a single category of entrainment (intra-individual, inter-individual, intra-group, or inter-group). For instance, investigating inter-group entrainment that takes place in the context of an Afro-Brazilian ritual, Glaura Lucas, Martin Clayton, and Laura Leante (2011) focused on inter-group entrainment, rather than observing the interactions that might take place between single individuals both within a group and beyond their own groups.

The term “social entrainment” suggested by Clayton et al. (2005) seems conceptually related to their claim that coordination among musicians—“entrainment to and through music” (Clayton et al., 2005, p. 7)—takes place within the realm of social interaction (cf. Clayton et al., 2005). Pointing to Christopher Small’s seminal work on musicking (cf. Clayton et al., 2005, p. 38), a term that refers to the understanding of music as an interactive social behavior (Small, 1998), Clayton et al. 2005 conceive of musical entrainment taking place in the context of musicking “as a particular case of entrainment in social interaction” (Clayton et al., 2005, p. 7). Based on Small’s notion that inter-individual interaction and communication are necessary conditions for musicking (Small, 1998), Clayton et al. logically infer that entrainment serves as a necessary condition for musicking: “If entrainment is a factor in any interpersonal interaction and communication, we should expect that it is a factor in any variety of musicking” (Clayton et al., 2005, p. 21). Although they do not discuss it in detail, Clayton et al. take McGrath and Kelly’s model into account (Clayton et al., 2005, p. 19 f.; Clayton, 2013, p. 25), and
consider it useful in bridging the gap between social sciences and neurological and biological research (see Clayton et al., 2005, p. 19 f.).

The purpose of bridging this gap has been pursued by the cognitive and biological psychologists Jessica Phillips-Silver, C. Athena Aktipis, and Gregory A. Bryant as well, in their article “The ecology of entrainment: Foundations of coordinated rhythmic movement” (Phillips-Silver et al., 2010). They first defined entrainment as coordinated rhythmic movement, which is based on the ability of an entrainable system to: 1) detect rhythmic signals in the environment, which can be ecological or social (i.e. rhythmic signals produced by another entrainable system); 2) produce rhythmic signals; and 3) integrate sensory information and motor production (cf. Phillips-Silver et al., 2010, p. 6). They also distinguish self-entrainment from social entrainment, and understand the latter as a “special case of entrainment in which the rhythmic signal originates from another individual” (Phillips-Silver et al., 2010, p. 7).

While Clayton et al. apply this concept to musical performance, Phillips-Silver et al. take into account the broader context of music research—including that of musicality, which plays a role also in areas such as motor perception, and can be observed during the interaction between music and dance. Attempting to develop a framework to study entrainment as musical behavior, Phillips-Silver et al. consider self-entrainment and social entrainment as different categories, and further refine the latter in the following subcategories (cf. Phillips-Silver et al., 2010, p. 8 f.):

Simple social entrainment is a form of unidirectional interaction between two entrainable systems, where only one rhythmic output functions as a rhythmic input for the other, but not vice versa.

Mutual social entrainment is a form of bidirectional interaction between two entrainable systems, where both entrainable systems use each other’s rhythmic output as rhythmic input.

Collective social entrainment involves more than two entrainable systems, among which a form of multidirectional interaction takes place. One rhythmic output can serve as rhythmic input for more than one entrainable system, but it is not necessary that the outputs generated by those systems all act as rhythmic inputs for the initial entrainable systems. Therefore, collective social entrainment is not a form of mutual interaction: “Though not every individual will necessarily use output from every other individual, collective entrainment can emerge within the group” (Phillips-Silver et al., 2010, p. 8).12

Phillips-Silver et al. do not conceive of intentionality as a necessary condition for social entrainment (cf. Phillips-Silver et al., 2010, p. 9), whereas “a shared social context” is considered necessary (Phillips-Silver et al., 2010); “[. . .] social entrainment may be facilitated by intentionality, but can also occur among systems that lack the cognitive complexity to process intentional components of signals” (Phillips-Silver et al., 2010). However, since Phillips-Silver et al. do not explore “the relation between entrainment and social behavior” but rather propose it as a topic for future research (Phillips-Silver et al., 2010, p. 11), it is not clear what precisely is meant by “social” in their term “social entrainment,” or by “intentionality,” which is regarded as a basis for “more complex and novel collective [. . .] behaviors” (Phillips-Silver et al., 2010).

To understand the concept of social entrainment, however, it is necessary to elaborate on the “sociality” of entrainment and the role of “intentionality.” In the following section, we return to McGrath and Kelly’s concept of social entrainment to assess their original contribution to entrainment research—placing emphasis on human social rhythms—and discuss what they mean by “social.”

### 2.3 McGrath and Kelly’s social entrainment model

Coining the term “social entrainment” to describe “the many human social rhythms that are influenced by other social rhythms or by external pacing events” (Kelly, 2010, p. 785), McGrath and Kelly (1986) stress the psychological and interpersonal aspects of entrainment that are not covered in physics and biology, proposing that this kind of social entrainment can occur at physiological, psychological and interpersonal levels (cf. McGrath & Kelly, 1986, p. 80; p. 86). Social entrainment occurs at every temporal level, although McGrath and Kelly find that social entrainment in ongoing interaction mostly happens on the ultradian level (ultradian, from Latin ultra and die, meaning “shorter than a day”). Their social entrainment model comprises both intra-individual and inter-individual entrainment and presents four component parts (see Figure 1). The first is rhythm, or “multiple endogenous [. . .] rhythmic processes” (McGrath & Kelly, 1986, p. 84). The second is mesh, a process of mutual entrainment or synchronization (McGrath & Kelly, 1986, p. 86), in which the rhythmic processes mutually entrain or synchronize with one another; as such, mutuality is a necessary condition of mesh, and consequently, of McGrath and Kelly’s model of social entrainment. The third is tempo, wherein mutually entrained and synchronized rhythmic processes result in temporal patterns of behavior. These three component parts lie in a causal chain. Outside of this causal chain, a fourth component part, pace (an external pacer event or entraining cycle), may take place and consequently change any of the other component parts (rhythm,
mesh, tempo). For example, if pace occurs, it may disturb tempo; having been disturbed, tempo returns to the original rhythmic processes, rhythm; rhythm will then adapt a new scheme, through mesh, for coordinating a new tempo. In this case, pace is external because it unidirectionally affects a system of rhythmic behavior, which may then lead to mutual interaction of rhythmic processes.

As an example of intra-individual social entrainment, McGrath and Kelly describe a flight across several time zones (cf. McGrath & Kelly, 1986, p. 86). All of the endogenous rhythms of an individual, for example sleep-wake rhythm and body temperature, are part of rhythm. A human’s internal rhythms are in a stable relationship to external rhythms such as the Earth’s rotation and the resulting local sunrises and sunsets—assuming he or she does not frequently travel across several time zones. Furthermore, endogenous rhythms are coupled to one another, and in synchrony (although this may be overstated, considering the chaotic nature of healthy brainwaves). But if this person is abruptly placed in a new local time zone, the synchrony among their endogenous rhythms, and the relationship of their internal and external rhythms, become disturbed. Consequently, a process of coordination and adjustment between the different rhythms must take place through mesh. The resulting temporal patterns of behavior—for example, a standard set of workday hours followed by many people—are called tempo.

Left alone over time, the endogenous rhythms adjust to the new exogenous rhythm—the new pace (i.e., the new time zone)—and the relationship stabilizes once again.

Ensemble performance offers a good example of inter-individual social entrainment. The playing of the individual musicians is rhythm; the negotiation between the musicians is mesh. It can be assumed that, starting from their individual rhythms, musicians pay attention to one another, possibly making use of hints and visual contact, and try to synchronize with one another. The resulting ensemble music is tempo. A pacemaker event could be rhythmic clapping by the audience, which can be disruptive for the musicians and therefore alter the tempo they had reached as a result of their negotiation. It should be noted, however, that negotiation is not a necessary condition for social entrainment; according to our interpretation of McGrath and Kelly’s text, negotiation and the adoption of a scheme for synchronizing individual preferences take place exclusively in the context of inter-individual (and not intra-individual) entrainment (even though the authors do not claim it explicitly).

The social aspect of this model primarily concerns mesh (social interaction) and pace (social influence). A social negotiation can take place during mesh, while pace can be considered a social component of the process due to both the ascription of social aspects to pace and the inherent aspects of pace that evoke social reactions. When mesh takes place in the context of inter-individual entrainment, the involved actors’ negotiation of temporal order or adoption of a scheme for synchronizing individual preferences play a central role (cf. Kelly, 2010, p. 785; McGrath & Kelly, 1986, p. 89), because, as Kelly notes, “[...] a mechanism [underlying human social behavior] must often be inferred” (cf. Kelly, 2010, p. 785). Therefore, McGrath and Kelly’s model of social entrainment comprises complex social interaction based on social cognition. This is not to say, however, that complex social processes such as negotiation and inferences of intentionality are required; the model also includes an individual’s (i.e., intra-individual) physiological and psychological processes as influenced by an exogenous rhythm in the social environment.

However, it is noteworthy that while McGrath and Kelly assign complex social processes, that is, high-order and long-term processes such as social negotiation and inference, to inter-individual entrainment, they assign more basal processes not involving social cognition solely to intra-individual entrainment. Considering that the process of social negotiation or inference presupposes (shared) intentionality or a relation to other representations (as discussed in social ontology, e.g., Searle, 1995; Tuomela, 2013), we can pose the question of whether social cognition is necessary for inter-individual entrainment. There are in fact cases of inter-individual social entrainment that do not involve a complex, high-order process (such as the interaction between newborn and caregiver, or that involved in free jazz improvisation; these will be discussed in more detail in the following section). Therefore, McGrath and Kelly’s use of “social” in “social entrainment” deserves critical discussion. We attempt to differentiate those inter-individual behaviors that can be described as “social,” aiming to develop a concept of sociality that can be related to social entrainment and musical interaction; this includes basal processes of inter-individual behavior that have not received much investigation in the social sciences in general, and in social ontology in particular.

3. Inter-individual behavior as social behavior

To differentiate this macro-concept as precisely as possible, we distinguish between four increasingly complex levels of inter-individual behavior. In some inter-individual social behavior:

a) social interaction is not necessary (5.1);

b) intentionality or inference is not necessary, even if social interaction takes place (5.2);

c) intentionality can play a role (5.3);

d) shared intentionality can play a role, when combined with semantic content (5.4).

3.1 Inter-individual behavior ready for social interaction, but not leading to it

This comprises both interpersonal behavior and animal communication; it consists of:
a) Two or more individuals perceiving their own and others’ behavior
b) Two or more individuals situated in a shared social context that affords or constrains each individual’s (p_i) selection of their behavior as well as the perception of their own and others’ behavior
c) Self-other difference
d) Behavior that emerges while each p_i is doing their own act (a_i).

Perceiving the behavior of one or more other individuals does not require thorough observation. The emerging behavior can include inter-individual entrainment. As an example: two swimmers of equal skill happen to swim in the same pool; the social context calls for them to avoid hindering each other when they swim at the same time, which typically leads to each swimming in their own lane. Because of wake flow, they may, however, end up swimming alongside each other at the same speed. Similarly: when two musicians rehearse individually but in close proximity at the same time, the social context prompts them to avoid distracting each other; nonetheless, if their individual pieces simultaneously reach an andante part, they may end up playing at the same speed.

This kind of inter-individual behavior that is not (yet) engaged in social interaction can be characterized as ready for social interaction; the individuals involved in this behavior can likewise be considered as a social group in a very broad sense. In the case of interpersonal behavior, each p_i is “a primary agent” (Tuomela, 2013, p. 15) having “purely private I-mode” intentions (Tuomela, 2013, p. 70); they “participate in [the] satisfaction [of this intention] […] qua private person (rather than qua group member)” (Tuomela, 2013). There is not a “we-mode group,” in which each p_i represents the group that normally also acts through group members’ actions. Each p_i’s I-mode intentions are afforded or constrained by a shared social context in this case; but they are not shifted to the “pro-group I-mode,” in which the group members share their private (personal) intention with the other group members (cf. Tuomela, 2013, p. 71).

The inter-individual entrainment that is reached in these two examples can however be characterized as social entrainment—to apply McGrath and Kelly’s term—especially considering their claim that even physiological and psychological processes can be mutually entrained to each other when they are influenced by an exogenous rhythm in the social environment. Our category is related to inter-individual rather than intra-individual physiological and psychological processes; however, inter-individual social entrainment resulting from a social context, albeit not based on social interaction, shares underlying mechanisms with the intra-individual social entrainment introduced by McGrath and Kelly.

### 3.2 Inter-individual behavior leading to social interaction, without any collective or “we-intentions”

This again includes both interpersonal behavior and animal communication; it entails:

a) Two or more individuals perceiving their own and others’ behavior
b) Two or more individuals situated in a shared social context that affords or constrains each p_i’s selection of their behavior as well as the perception of their own and others’ behavior
c) Self-other difference
d) Performing a_i in a causal relation to b), comparable to pushmi-pulwyu representations\(^\text{14}\)
e) Behavior that emerges in the course of reciprocation, not necessarily derived from any collective or “we-intentions.”

The emerging behavior can include inter-individual entrainment based on social interaction. However, this interaction does not necessarily involve “we-intentions”—to apply John Searle’s term (Searle, 1990, 1995). If p_i is aware of the effect (e.g., entrainment) that is reached through inter-individual behavior, this type of inter-individual behavior can be regarded as a form of collectivity which does not necessarily involve “goal-directed behavior in the time” (Searle, 1990, p. 414), and can serve as “the precondition of collective intentionality” (Searle, 1990).

There are many examples for this category of inter-individual behavior. For instance, if a very young child non-verbally entrains to a rhythmic pattern created by their caregiver—as demonstrated among nine-month-old infants in an empirical study by Ruth Feldman and her colleagues (Feldman et al., 2009)—, that social interaction is neither planned nor based on intention, nor does the child have any explicit knowledge of what category those rhythmic patterns (e.g., musical patterns) belong to. This type of inter-individual coordination also happens when moving, influencing, and/or being influenced by one or more other individuals’ behavior, as in the case of walking together (cf. Miles, Nind, & Macrae, 2009; van Ulzen, Lamoth, Daffertshofer, Semin, & Beek, 2008), and can be characterized as “unintentional interpersonal coordination” (cf. Richardson, Marsh, & Schmidt, 2005; for a review see Marsh et al., 2009). Paradigmatic examples for unintentional inter-personal coordination include behavioral coordination during social interaction, such as postural coordination (Bernieri & Rosenthal, 1991; Chartrand & Bargh, 1999; LaFrance, 1982), gestural adjustments to speech acts (Condon & Ogston, 1966; Kendon, 1970), and entrainment of bodily rhythms during joke telling (Schmidt, Nie, Franco, & Richardson, 2014). The symbiotic interspecies relationship between cleaner fish and other predatory fish is likewise of this type. Cleaner fish feed off of the parasites and excess scales of larger predatory fish; although the larger
3.3 Collective inter-individual behavior involving "we-intentions"

This kind of behavior is not necessarily verbally mediated; it includes both interpersonal behavior and animal communication, and consists of:

a) Two or more individuals perceiving their own and others’ behavior
b) Two or more individuals situated in a shared social context that affords or constrains each pi’s selection of their behavior as well as the perception of their own and others’ behavior
c) Self-other difference
d) Perception of difference between their own behavior and one or more other individuals’ behavior
e) Each pi is performing ai as part of performing a collective act A; each pi makes “a specific contribution to the overall goal” (Searle 1990, p. 403)
f) Adjustment or complementation of an individual’s behavior to the behavior of one or more other individuals (not only through entrainment).

The individuals’ intentions to participate in a collective act A are derived from the overall goal of the collective behavior in such a way that each pi believes that they are doing ai as part of their doing A (cf. Searle, 1990, p. 407). This category concerns collective activity involving “we-intentions.” Weaker than collective intentionality, Searle conceives of “we-intentions” as primitive (cf. Searle, 1990, p. 404): “the individual «I intend»s are […] derivative from the «we intend»s” (Searle, 1990, p. 403); “«I am doing A» is derivative from the collective intentionality, «We are doing A»” (Searle, 1990). Collective inter-individual behavior involving “we-intentions” differs from the summation of individual acts, in that the former is oriented towards cooperation with a common goal (cf. Searle, 1990, p. 406). More precisely, not every act that happens to result in a common goal gives rise to collective behavior; rather, collective behavior is accompanied by each pi’s intention that can be expressed with reference to the others. This intention, however, is not supra-individual, but possessed by individual agents (cf. Searle, 1990, p. 407).

This behavior is found, for instance, when children (by the age of 18 months) play a social game with adult partners (cf. Warnecken et al., 2006; Tomasello and Moll, 2010), several persons cooperatively pull a car to get it started, audiences continue to applause to demand an encore, which can result in entrained clapping (cf. Neda, Ravasz, Brechet, Vicsek, & Barabasi, 2000), or musicians improvise together without having explicitly defined roles or shared semantic content.

3.4 Collective inter-individual behavior based on shared or collective intentionality

This consists of:

a) Two or more individuals perceiving their own and others’ behavior
b) Two or more individuals situated in a shared social context that affords or constrains each pi’s selection of their behavior as well as the perception of their own and others’ behavior
c) Self-other difference
d) Perception of difference between their own behavior and one or more other individuals’ behavior
e) Each pi is performing ai as part of performing A, while having a shared intention with a partially identical semantic content
f) Adjustment or complementation of an individual’s behavior to the behavior of one or more other individuals (not only entrainment), while actively pursuing the overall goal.

Singing in a choir or playing in an orchestra offers an example: each pi has a “we-mode” (Tuomela, 2013), which is a strong kind of collective intentionality with a common goal, a shared semantic content, and explicitly, specifically defined roles. In an orchestra concert, a violinist who is an orchestra member intends to advance the collective goal—together with other orchestra members—by playing their violin part. They believe that other members of the group also intend to do so, and know that their A is based on the same musical score and guided by the same conductor’s instruction. Each pi is a “representative acting for the group” (Tuomela, 2013, p. 15).

3.5 Summary of inter-individual behavior as social behavior

Our four categories of inter-individual social behavior comprise forms of social behavior which are basal and do not involve social cognition, and therefore are not covered in social ontology (categories 1 and 2; see sections 3.1 and 3.2). They concern inter-individual behavior based on the perception of one’s own and others’ behavior and a causal motor reaction to it, which is afforded or constrained by a social context. Even when it does not result in social
interaction, this kind of inter-individual behavior is formed by a social context and, consequently, differs from purely physical or biological behavior (category 1). When such inter-individual behavior is due to social interaction, yet does not involve any collective and “we-intentions,” it concerns a form of social interaction which is basal in the sense that individuals causally react to others’ behavior reciprocally, based on a perception-action cycle comparable to pushmi-pullyu representations (category 2). Inter-individual behavior that falls into these two categories can be observed in proto-musical behavior such as a caregiver’s infant-directed speech or an infant’s pre-verbal communicative gestures (cf. Malloch & Colwyn, 2009).

More complex forms of inter-individual social behavior involve shared intentions in a weak sense (category 3; see section 3.3) and in a strong sense (category 4; see section 3.4). Sophisticated musical practices, such as Western music from the common-practice period, are based on collective intentionality, and are combined with a semantic content so as to prove to be group actions established through generations and history (category 4). However, in some musical contexts, such as that of free jazz, music-making and music perception can be based on a loose cooperation among individuals (musicians) rather than on a social norm; this kind of cooperation is derived from a collective goal rather than from a personal intention (category 3). Sometimes, a musical practice such as a folk ritual arises without any intention to produce or reproduce a specific piece of music; but this kind of practice, even if it is partially a speech act, such as a shaman’s prayer, can be identified as musical rather than linguistic. Differentiating among these four categories of inter-individual social behavior allows for a more precise integration in the context of music research of the musical practices in which entrainment can emerge.

4. A new conceptualization of social entrainment

Extending McGrath and Kelly’s concept of social entrainment by taking into account our categories of social behavior clarifies how social entrainment is different from and irreducible to physical and biological entrainment. Social entrainment indicates the entrainment of human rhythmic behaviors from those which are basic incidental to those which are complex intentional, which are embedded in a social context and can be influenced by psychosocial factors such as social competences and social motives. This in turn allows for new social configurations such as social identity, social bonding, and affiliation.

When adopting the physicalist view that thoughts supervise upon brain processes, one might assume that some cases of psychological or physiological self-entrainment—which McGrath and Kelly consider social entrainment—would be reduced to neural entrainment. Although neural entrainment is necessary for the perception and production of social rhythmic behavior, a social context, which all of the self-organizing systems that produce rhythmic social behavior are situated in, affords or constrains each individual’s perception and selection of behavior. This means that a social context can facilitate even spontaneous entrainment, and does not strongly impose “high power” forced entrainment (see Collier & Burch, 1998, p. 165). Therefore, the spontaneous process (including selection of behavior) may be characterized as the foundation of social entrainment—thereby distinguishing social entrainment from physical and biological entrainment.

A number of empirical studies show that interpersonal coordination, including mimicry and entrainment, occurs to a different degree depending on the propensity to coordinate with each other, which can be influenced by social rapport (Bernieri, 1988; Bernieri, Gillis, Davis, & Grahe, 1996), other-directed focus (Lakin & Chartrand, 2003; van Baaren, Maddux, Chartrand, de Bouter, & van Knippenberg, 2003), social value orientation (Lumsden, Miles, Richardson, Smith, & Macrae, 2012), and likability (Zhao et al., 2015). Moreover, if two or more groups situated in a shared social context entrain to one another, this entrainment can involve a high-order social process related to the group not only consists of each group member’s action, but also itself acts as a group and has a collective goal (cf. Bargh & Chartrand, 1999; Chartrand & Jeferis, 2003). In this case, a complex, long-term process such as the negotiation and inference of another group’s intentions can underlie social entrainment. Such a process renders social entrainment irreducible to physical and biological entrainment.

5. Musical social entrainment

Based on this new conceptualization of social entrainment, we propose the term “musical social entrainment” to refer to intra-individual, inter-individual, intra-group, and inter-group entrainment to exogenous musical rhythms—including the rhythms of other musically acting individuals and groups—embedded in a social context and contributing to sociality. This term is similar to Clayton et al.’s “musical entrainment”: “entrainment to and through music” (Clayton et al., 2005, p. 7). It differs slightly, however, from “social entrainment” as used by Clayton et al. (2005) and Phillips-Silver, Aktipis, and Bryant (2010), which also refers to entrainment achieved in the context of musical practices; they exclude intra-individual entrainment from social entrainment, whereas we subsume intra-individual entrainment to musical rhythms under the term “musical social entrainment.” Moreover, “musical social entrainment” also encompasses the inter-individual entrainment that can take place in a music-related social context even when it is not based on social interaction (as described in section 3.1). Our view also differs from Clayton et al.’s notion of entrainment occurring in musicking, which treats musical entrainment as “a particular case of
entainment in social interaction” (Clayton et al., 2005, p. 7); for us, social interaction is not a necessary condition for “musical social entrainment.”

The perception of musical meter is an example of intra-individual entrainment to musical rhythms. Listeners do not pay equal attention to all tones and sound sequences. Auditory attention is instead directed towards relevant moments of musical events in such a way as to coincide with those moments (Huron, 2006, p. 176). Such a process is described in terms of entrainment in the dynamic attending theory (DAT). In DAT, entrainment refers to a biological process through which neural oscillations synchronize with an external event (Jones, 2011, p. 83). Neural oscillations, which are generated through mechanisms within single neurons and through their interaction, are rhythmic, recurrent electrochemical activities in the brain and central nervous system. A neural oscillation is characterized as its own frequency, amplitude, and phase. According to the resonance theory (Large, 2008), spontaneous neural oscillations are generated by a nonlinear oscillator even without having any external stimulus (Large, 2008, p. 203) and are able to synchronize with an external stimulus and then to return to their own frequency. In music perception, meter is considered the result of perceiver’s entrainment with musical surface (London, 2012). Meter is perceived if a metrical structure is mentally represented and a strong neural entrainment with the frequency of meter results from this mental representation. Metrical entrainment involves a number of coordinated autonomous oscillators generating neural oscillations, which rise with the beat frequency to its sub-harmonics (Nozaradan, Peretz, Missal, & Mouraux, 2011). Temporal invariants in music are detected in establishing meter in music perception due to human capacity for entrainment to rhythmic signals. The music theorist Justin London therefore characterizes musical meter as an entrainment behavior (London, 2012).

Musical meter that is regarded as entrainment behavior is concerned with musical social entrainment since, while perceiving musical meter, endogenous rhythms are entrained to one another with respect to the sequence of musical sounds, which is embedded in a socio-cultural context. A recent study by Jan Stupacher et al. (Stupacher, Wood, & Witte, 2017) shows that entrainment to musical rhythms has a stronger social effect compared to entrainment to an isochronous pulse. Stupacher et al. conducted a tapping experiment under four conditions: experimental subjects tapped either 1) to the beat of music, or 2) to an isochronous metronome; each of these exercises took place joined by an “experimenter” who tapped either 3) synchronously or 4) asynchronously. Following this tapping task, the subjects were involved in a further implicit task, in which they helped the experimenter collect pencils that had dropped from a table. The subjects tended to be more helpful in picking up pencils when assisting the experimenter who tapped synchronously to the beat of music; no such effect was found under the conditions involving a metronome (Stupacher et al., 2017). Tapping to an isochronous metronome could result in intra-individual entrainment in this experiment; however, it cannot be conceptualized as social entrainment since there is no social context. This study also indicates the need to distinguish musical social entrainment from other kinds of entrainment.

The distinction between musical and isochronous stimuli that Stupacher et al. took into account for their experimental design provided the premise of another study by Marta Rizzonelli, Kim, Gladow, and Mainka (2017), which focused on musical feedback in gait training for Parkinson’s disease. In line with the results that Stupacher et al. found in healthy subjects, Rizzonelli et al. (2017) observed that Parkinson’s patients who had the task of walking along to an acoustic stimulus (provided through headphones) tended to develop more precise entrainment patterns when listening to real-time musical feedback than to isochronous metronome beats. This outcome follows partly from the nature of biofeedback, but also from the nature of musical texture, which provides more timing information, motivation, and emotional involvement than isochronous beats. Taking into account the results of this study, it can be assumed that the social context in which the music has been conceived, and which the music reminds the listener of, plays a fundamental role in the facilitation of entrainment.

Regarding musical social entrainment in inter-individual, intra-group, and inter-group contexts, the first level of social behavior described in section 3.1 (inter-individual behavior ready for social interaction, but not leading to it) does not apply to musical practices that are embedded in a context of musical performance, and is rarely found in real-world situations. Therefore, in the following, we consider three increasingly complex levels of social behavior (categories 2, 3, and 4; see sections 3.2, 3.3, and 3.4), which can be observed frequently in common musical practices and are reflected in numerous musicological studies.

An ethnomusicological study on inter-group entrainment carried out by Glaura Lucas, Martin Clayton, and Laura Leante (Lucas, Clayton, & Leante, 2011) examines an example of inter-individual behavior leading to social interaction without any collective or “we-intentions” (section 3.2). The study analyzes an Afro-Brazilian religious ritual called Congado, where different communities are supposed to avoid entrainment with one another—that is, avoid playing together—to better display their differences. Of course, the ritual as a whole involves intra-group and inter-group forms of interaction that are complex from both the musical and the social point of view, involving collective intentionality and allowing musicians to reach intra-group entrainment while simultaneously avoiding inter-group entrainment. We focus on a specific case analyzed in the article in which entrainment occurs as a basic incidental interpersonal behavior, without any collective or “we-intentions.” This happens when two communities that
approach each other for a formal greeting entrain despite their intention not to do so.

According to Lucas et al., the described incidental event of a single individual entraining with a group different from his, that is, a musician’s temporary change of affiliation, which at the same time leads to musical inter-group entrainment, is due to close spatial proximity and visual contact (Lucas et al., 2011, p. 77). In this case, entrainment that clearly goes beyond the limits of the individual groups and creates a form of social interaction seems to be engendered by factors other than collective or “we-intentions”: visual contact, that Lucas et al. emphasize, may have had a psychosocial impact on the inter-group level. But other factors of social interaction could also have led to this kind of musical social entrainment among musicians who interact socially without any collective or “we-intentions”: 15 for instance, external pacemaker events (e.g., honking cars or striking clocks) may have disturbed group coordination that falls into collective intra-group/inter-group behavior based on shared or collective intentionality. This example shows how basic incidental forms of entrainment may take place even in complex, highly-structured and codified contexts, and clarifies how, in real-life situations, different categories of inter-individual behavior can intertwine. However, cases of this sort are not music-specific, as is evident in research on interpersonal behavioral coordination that takes place during social interaction, like gestural coordination during speech communication (mentioned in section 3.2). Nonetheless, it can be assumed that such forms of entrainment that are observed not only in other behaviors accompanying the communicative act, but also in the communicative act itself, occur more frequently in musical practices as compared to speech acts.

Concerning more complex forms of musical social entrainment that fall into the categories “collective inter-individual behavior involving we-intentions” and “collective inter-individual behavior based on shared or collective intentionality,” we may consider music-specific forms of entrainment, for instance, those that occur in conjunction with “groove” or expressive musical timing. Unlike those examples given in section 3.4 of singing in a choir or playing in an orchestra, this kind of entrainment is rarely observed outside of musical interaction. Therefore, we propose the term “music-specific social entrainment” for this kind of musical social entrainment.

Groove—“a persistently repeated [sound] pattern” (Kernfeld, 2002) or “an unspecified but ordered sense of something that is sustained in a distinctive, regular, and attractive way, working to draw the listener in” (Feld, 1988)—is a phenomenon of music which, according to Charles Keil, is “full of discrepancies” (Keil, 2013, p. 279), including being “out of time” (Keil, 2013). The ethnomusicologist Mark Russell Doffman considers the concept of entrainment a theoretical and methodological building block for understanding the cognitive underpinnings of groove (Doffman, 2008, 2013): “I make the case for entrainment not just as a sensorimotor process that can explain musicians’ shared temporal negotiations but also as a process that is deeply felt by musicians and explored in their discourse as ‘groove’” (Doffman, 2013, p. 62).

Doffman uses relative terms of groove in combination with the modifiers “tight” and “loose” to describe the mismatch between musicians over three consecutive musical onsets: if the mismatch is less than 40 ms, the groove is considered tight; if the mismatch is greater than 60 ms, the groove is considered loose (Doffman, 2008, p. 238f). The terms “tight” and “loose” are also used to characterize the trend or development of groove over time. If two musicians reduce their inter-onset intervals, their play becomes tighter, whereas if they increase their inter-onset intervals, their play becomes looser. Furthermore, concerning some interviewed musicians who related groove to awareness, Doffman suggests that descriptions of a change in the “consciousness or sense of being with others in some way […] may be understood in terms of the degree of entrainment” (Doffman, 2013, p. 84). On the topic of awareness, Doffman agrees with Charles Keil’s theory of participatory discrepancies (Keil, 1995), claiming that, as the timing discrepancies between musicians diminish, less conscious awareness is required to understand the timing of the other performers—thus opening up opportunities for active thought. The play and practice of most ensembles, including the small jazz bands that were studied by Doffman, can be classified as collective inter-individual behavior based on shared or collective intentionality (see section 3.4). Groove that emerges in the process of collaborative musical shaping is based on “a cultural norm, a feeling for how things should be between players” (Doffman, 2013, p. 78), and participants pursue that goal while filling their distinct and separate roles. If the roles are not so strictly defined and the semantic contents of the musician’s intentions are incongruent, such as in free jazz, groove is “inflected by intersubjective temporal models” (Doffman, 2008, p. 295). In those cases, the collective inter-individual behavior involves “we-intentions” (see section 3.3) rather than actual collective intentionality. As such, groove that can be defined as “the musical feeling of entrainment” (Doffman, 2008, p. 295) is the result of collective inter-individual behavior.

Another case that we consider for music-specific social entrainment in the context of ensemble performance is expressive timing, which includes asynchronies in onset time of simultaneous tones, not only on a micro-level, but also on a macro-level. Performers of common-practice period in Western music try to avoid asynchrony in most cases but tend to embrace it in the course of performing music expressively—for example in rubato. In their article “The application of entrainment to musical ensembles,” Tomoyoshi Yoshida et al. coin the term “soft entrainment,” 16 which comprises regularly alternating partial synchrony and partial asynchrony (Yoshida, Takeda, & Yamamoto, 2002, section 1)—both elements that musical
performers exploit to create expressiveness. As noted in section 2.1, synchrony refers to correlations of two or more events, whereas synchronization refers to the process of rhythms that adjust to each other until they reach a constant phase difference. However, Yoshida, Takeda, and Yamamoto (2002) seem to understand synchronization as synchrony: “Synchronization is defined as the situation in which multiple oscillators share a common period. Entrainment means both the process of developing from the initial conditions to synchronization and the synchronization itself” (Yoshida et al., 2002, section 3). Evidently, entrainment here refers to a process through which synchrony is achieved. Nonetheless, “synchronization” is also used by Yoshida et al. to indicate a process: “While the process of synchronization in music is not easily explained […] , the new notion of entrainment should thus be applied to high-order phenomena like music” (Yoshida et al., 2002, section 1.3). To rectify this misleading terminology, we propose to use the terms “partial synchrony” and “partial asynchrony” instead of Yoshida et al.’s “partial synchronization” and “partial asynchronization,” as we proposed distinguishing synchrony from synchronization in section 2.1.

The phenomena of partial synchrony and partial asynchrony are described by Yoshida et al. as “tenseness” and “relaxation” (Yoshida et al., 2002, section 4), which are applied to a theory of rhythm. Based on certain music theoretical considerations (e.g., Eugene Narmour’s expectation-based implication-realization model; see Narmour, 1990), a basic rhythmic pattern is regarded as being divided in two parts. The first part tenses and leads to the point of synchrony (climax); the second part relaxes and “deviates” from the climax (Yoshida et al., 2002, section 3). In a revised model that fits typical music phrases, there are two points of synchrony (one at the beginning and a climax near the end), and two points of asynchrony (which deviate from the two synchronized points). The original aspect of Yoshida et al.’s article is that asynchrony is included within the concept of entrainment—which is therefore characterized as soft.

In the case of ensemble performance of an established piece of music that Yoshida et al. consider, group’s coordination is based on a social norm about musical expressiveness and the organization of musical rhythm within a musical genre. Therefore, expressive ensemble performance can be regarded as collective inter-individual behavior based on shared or collective intentionality (see section 3.4), which can result in social entrainment.

Yoshida et al.’s “soft entrainment” and Doffman’s groove share a controversial characteristic. Yoshida et al. basically combine partial synchrony and partial asynchrony in the single concept of “soft entrainment.” This is not a softening of entrainment, but a conflict with its physical definition. Admittedly, “soft entrainment” could have advantages when talking about musical expressiveness, because both synchrony and asynchrony are used in musical performance to create “vivid expression through musical performance” (Yoshida et al., 2002, p. 1). Likewise, Doffman also includes “permissible asynchrony […] within the bounds of groove” (Doffman, 2013, p. 84). This indicates the need for a single, easy-to-use term that describes the coalescence of partial synchrony and partial asynchrony, doing justice to imperfect rhythmic adjustments in music-specific social entrainment. Although the concept of music-specific social entrainment, which includes the process giving rise to asynchrony, is not compatible with the physical and biological concept of entrainment, it deserves thorough discussion, especially concerning the question of whether parts of ensemble music that are asynchronous would be achieved by (albeit not perfect) synchronization and how this phenomenon could be characterized properly. The term “asynchronization,” which is used by Yoshida et al. and by Rudolph A. Rasch (Rasch, 1979, 1988) to characterize this kind of process leading to asynchrony in ensemble music performance, is misleading, in the sense that it precludes the possibility that some states that are asynchronous at a given point in time can also be achieved through synchronization that also includes events related by a constant phase difference. Nevertheless, Rasch offers relevant arguments to explain how human beings do not perceive those musical events that are asynchronous from a merely acoustic point of view as asynchronous (Rasch, 1979, p. 130): When listening to musical events, human attention and perception are focused not (only) on timing, but on a number of musical parameters including timbre, pitch, and melodic development over time. Additionally, timing irregularities can occur due to the complexity of rhythmical or metrical structure, codified musical techniques such as ritenuto, accelerando or ritardando, or notes being preceded by a rest. Music, and consequently music-specific social entrainment, involves peculiarities that need to be considered in their uniqueness and cannot be assimilated to other communication systems or to other cases of social entrainment.

6. Conclusion and discussion

The present article aimed at discussing the concept of social entrainment thoroughly, developing our own categories of social behavior and estimating whether and to what extent this concept is appropriate to characterize the process of entrainment that takes place in musical practices. A relevant problem is the adaptation of the term “entrainment” borrowed from physics to the field of social (musical) research. Clearly, the terminology of physics refers to quantifiable parameters that are insufficient to the analysis of social behaviors such as those found in music performance or musical practices. In our opinion, to avoid category errors, it is necessary to clarify what exactly is being investigated and what results are expected. For example, when observing the phase relationship of two
musicians playing, it should be described how this parameter is observed, whether its analysis needs to be integrated with further exploratory methods, and what explanatory power the results of each method are supposed to have. Furthermore, any social context—which individuals and groups that produce rhythmic social behavior are situated in—should be explicitly discussed. Last but not least, the forms of (musical) social behavior should be differentiated to better investigate social entrainment, since (musical) social behavior does not always involve shared intentionality, as Phillips-Silver et al. 2010 noted. However, since shared intentionality plays a significant role in certain musical practices—mostly in the musical tradition where the concept of closed work is dominant—it would be helpful for scholars investigating entrainment that occurs in musical practices to categorize social behavior. Moreover, we would need to explore how the process of entrainment is afforded or constrained by a social context, and whether a high-order process such as “negotiation or [... ] adopt[ison of] a scheme for synchronizing individual preferences” (Kelly, 2010, p. 785) is performed during the musical practices. This exploration allows us to infer the degree of symmetry between the individuals. This is of particular interest if what Phillips-Silver et al. 2010 refer to as collective social entrainment (which results from the interaction of a group of more than two individuals) is involved.

In music research, the term “social entrainment” has so far been limited to inter-individual and inter-group entrainment. According to McGrath and Kelly (1986), however, intra-individual entrainment—often called self-entrainment—is also subsumed under “social entrainment.” Highlighting this difference, we claimed that the relatively simple mechanisms underlying intra-individual social entrainment can also be fundamental to the basic incidental forms of inter-individual social entrainment introduced in section 3.1 and 3.2. Developing different categories of social behavior, we tried to complement missing explanations for the concept of social entrainment, as was partially the case in McGrath and Kelly’s model. Based on our categorizations, we proposed understanding social entrainment as entrainment of human rhythmic behaviors, which include both basic incidental and complex intentional behaviors on intra-personal and interpersonal levels. These behaviors are embedded in a social context, and can be influenced by psychosocial factors and contribute to sociality as well. Finally, we coined the new term “musical social entrainment” to refer to intra-individual, inter-individual, intra-group, and inter-group entrainment to exogenous musical rhythms—including the rhythms of other musically acting individuals and groups—embedded in a social context and contributing to sociality.

The concept of social entrainment makes it clear that considering musicians as oscillators or rhythmic processes is just the starting point. As to future research perspectives, we therefore need to explore new methods to further develop empirical studies of social entrainment underlying musical practices; until now, these have been conducted primarily by adopting methods developed in physics and biology. In exploring new methods for study, we might gain insight into the diverse factors and processes influencing social entrainment that takes place in a musical context, while accounting for those necessary conditions for entrainment observed in physics and biology. As we mentioned in section 2.1, synchronized/entrained systems have the natural disposition to reassert themselves after a perturbation as a necessary condition. This predicted reaction of the system of oscillators to either global or local perturbations allows us to test from a bottom-up perspective whether a seemingly synchronous state has been initiated by causal interaction—in which case we use “synchronization”/“entrainment”—or by chance. However, the perturbation method has some limitations. First, perturbation does not completely rule out happenstance: a chaotic system that happens to react to a specific perturbation with a seemingly synchronous state by chance could still be misinterpreted as a synchronized/entrained system caused by interaction, if there is only limited amount of measurements. Second, while the reaction of a system to perturbation allows to identify synchronization/entrainment, it still does not clarify the social dynamics that have led to it. In the context of a musical activity or performance, social behavior cannot be underestimated, let alone ignored. We propose to combine the physical analysis of entrainment with suitable methods coming from cognitive anthropology, ethology, and social sciences. Structured observation, also called “systematic observation” (Robson, 2002), which is typically used for data collection in social science and ethology to determine whether and in which order interaction takes place, is one candidate. It is distinguished from other kinds of observational methods by the use of specifically trained and calibrated human observers to record the occurring frequency respectively duration of specific events, by means of coding schemes. Coding schemes are “predefined catalogs of behavioral codes” which “specify which behavior is to be selected from the passing stream and recorded for subsequent study” (Bakeman & Gottman, 1997, p. 4). Thus, structured observation provides the possibility to use the genuinely qualitative method of observation as a quasi-quantitative method. Some interview methods that can be combined when focusing on particular dimensions of the experience related to (social) behavior and entrainment are appropriate to investigate subjective experience: the micro-phenomenological interview technique, self-confrontation interview, and video-stimulated recall and reflection. The technique of the micro-phenomenological interview that has been developed within the scope of neurophenomenological research programs since the 1990s aims at producing a model for the generic structures of experience, accounting especially for its
temporal unfolding (cf. Petitmengin, Van Beek, Bitbol, Nissou, & Roepstorff, 2017). Self-confrontation interview is a method that is currently being explored in cognitive anthropology (cf. Theureau, 2010). This method uses either a situation similar to that in which the experience to be investigated took place, or a video recording of that event, to help the interviewee to remember her or his experience and thus enable self-confrontation. Using the technique of video-stimulated recall and reflection, a subject’s memories are stimulated with video sequences, prompting them to reflect on their thoughts and decision-making as they see it unfold during the recording. It is particularly effective in the self-analysis of interactional processes such as collective music-making. In this way, it would be possible to examine musicians’ social and musical roles (e.g., leader and follower during a music performance or musical practice), musical intentions, motivations, and/or perceived groove and expressiveness, which cannot be inferred through audio analysis data alone but are valuable indicators of cause and effect.

If we relate musical social entrainment to the feeling of musical expressiveness and shared timing as experienced by musicians while shaping music together—what we term “music-specific social entrainment”—we should also ask whether partially asynchronous states that are observed in musical practices are achieved due to imperfect rhythmic adjustments. Since music-specific social entrainment is to some extent physically measurable, it would also be of interest to physicists and biologists to ask what implications the investigation of music-specific social entrainment has for current research on entrainment. How can musicians constantly be in time together, albeit not perfectly synchronized? The investigation of this question would likely challenge the physical and biological concept of entrainment. That being said, further investigation of musical entrainment using methods of measuring physical parameters would allow for taking seemingly asynchronous states into account when developing a concept of entrainment that can be used for musical contexts. This view of musical social entrainment can be seen as the result of social behavior, as it requires the concept of gradualness to fully encompass the various cases, such as “[f]the experience of ‘being in the groove’,” that can occur in musical practices (Doffman, 2013, p. 62). Such an investigation of musical social entrainment would give rise to a re-thinking of the physically and biologically oriented concept of entrainment; and perhaps it could open this concept, so that the mechanisms of what can be referred to as “entrainment”—also in the physical and biological sense—can be better understood.

Authors’ contributions

JHK conceived the concept of musical social entrainment and the categories of inter-individual behavior as social behavior (session 3). JHK, AR and MR jointly wrote the manuscript within the scope of the study group of systematic musicology “Musical Entrainment” at the Humboldt University of Berlin.

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Notes

1. The term “musical practices” is used to include both musical performance and non-performative practices—such as a musical interaction between infant and caregiver (cf. Kim, 2017). Ian Cross (2014) conceptualizes music as a “communicative practice” (Cross, 2014, p. 809), subsuming under this term musical performance, musical rituals, therapeutic practice, and so on.
2. In this context, “adjust”—from the Late Latin adiuxtare (to bring near)—indicates two or more quantities becoming temporally closer to one another (adjustment of frequencies, adjustment of rhythms).
3. In the context of physics, we understand “oscillator” as any animate or inanimate body that produces oscillations, from a pendulum clock to a musician striking piano keys according to a periodic pattern. Consequently, an oscillation is not necessarily a repetitive movement back and forth, but rather the pattern of a wave representing a repetitive event.
4. This phenomenon is traditionally referred to as synchronization, rather than entrainment. To name a few references: Granada et al., 2009; Kelso, 1995; Manevitch & Gendelman, 2011; Pikovsky et al., 2001. To our knowledge, Clayton is the first to ascribe “entrainment” to Huygens’ phenomenon (Clayton et al., 2005). However, “synchronization” and “entrainment” often seem to be used interchangeably.
5. “Le phénomène de la sympathie, sympathie des horloges,” quoted from Pikovsky et al., 2001, p. 3.
6. Clayton et al. 2005 explicitly refer to Pikovsky et al. 2001.
7. The notion that “entrainment” is more appropriate than “synchronization” for this kind of unidirectional process was also supported by the chronobiologist Hanspeter Herzel, professor of theoretical biology at the Humboldt University of Berlin, in a personal communication in April 2017.
8. For the definition and application of relative phase see Clayton et al., 2005, p. 62 f.; p. 75.

9. Sometimes the term “interpersonal entrainment” is used. We advocate using the term “inter-individual entrainment” since we are discussing the concept of social entrainment, and thus taking different forms of inter-individual behavior—which might include animal behavior if necessary—into account.

10. Here it should be noted that, according to McGrath and Kelly (McGrath & Kelly, 1986), self-entrainment is also a form of social entrainment; a detailed discussion follows in this section.

11. For a detailed discussion see Lucas et al., 2011, section 5.

12. Contrary to this position, Geeves et al. (2014) define collective social entrainment as “mutual social entrainment occurring across more than two parties, such that there is a network of input/output connections created between more than two individuals in a group” (Geeves et al., 2014, p. 2).

13. This figure is a modified version of McGrath and Kelly’s “Figure 4-1. The social entrainment model” (McGrath & Kelly, 1986, p. 85). We decided to break up the arrow lines originating from pace, because it is not part of the causal chain (rhythm → mesh → tempo) and only “potentially has an impact on each of the other three components” (McGrath & Kelly, 1986, p. 86).

14. Pushmi-pulpyu representations are often used in animal communication, such as a bird’s alarm call; they have both a descriptive and a directive function (Millikan, 1995).

15. Lucas et al.’s study does not elaborate on the question of which factors engendered this kind of entrainment, since they use an ethnographic interview rather than an in-depth interview, in conjunction with physical measurements of the relationship between audio data.

16. Although the modifier “soft” might suggest a corresponding antonym—such as “hard entrainment”—none is mentioned in the article.

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