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TOP-DOWN TO BOTTOM-UP: RHYTHMIC SYNCHRONY RELAXES SOCIAL PRIORS TO ENABLE CHANGE

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Short Abstract

Rhythmic synchrony elicits rewards and bonding but also relaxes social boundaries, sometimes drawing authorities' ire. Its remit thus seems broader than encouraging "groupishness." Here, I describe the *relaxed priors through synchrony* (RePS) model, in which high-precision, temporally granular bottom-up signals for beat perception and synchronization loosen precision for social priors with broader temporal scope. Synchrony thereby weakens normative predictive models, which can then be swiftly revised at pivotal social moments. This entropic state produces trance at extremes. Authorities don't always like it, but synchrony enables anti-structure, reorganization, and change. This, not merely social bonding, is its basic human function.

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Long Abstract

Interpersonal synchrony, such as dancing to a shared rhythm, elicits bonding and rewards, leading many to see it as a mechanism for group cohesion. Yet synchronized activities also reduce ingroup bias, rapidly bond strangers, flatten hierarchies and blur roles, and evoke trance states. Synchrony thus softens many boundaries that "groupishness" requires. Perhaps in consequence, cultural authorities frequently condemn expressive dance music rather than embracing it as a tool for social cohesion. Aiming to account for these multifarious features, this review integrates findings from cognitive motor science, biomusicology, and adjacent fields to synthesize the *relaxed priors through synchrony* (RePS) model. Highlighting synchrony's effects on high-level social predictive processing, RePS depicts the sensorimotor signals associated with beat perception and synchrony as lending precision to bottom-up prediction error at temporally granular (< 2-second) scales. Precision for abstract social priors is thereby reduced, inverting the social brain's characteristic "top-heaviness." With categorical beliefs about roles and groups no longer scaffolding coordination and joint action, local-timescale planning and processing evoke low psychological construal. Tighter links between motivation and reward facilitate disinhibited enjoyment orthogonal to status and group boundaries. In the entropic cognitive state that results, relaxed social priors are more easily revisable, enabling coordinated change and updating, as in ritual celebrations. This model affords rich opportunities for empirical testing and interdisciplinary theory-building. Overall, RePS explains why authorities frequently dislike synchrony, why dance plays centrally in social transitions such as weddings, and why rhythmic music is associated with trance. More than a bonding device, synchrony facilitates change.

Keywords: anti-structure, beat perception, construal level; entropy, joint action, precision, predictive processing, rhythm, ritual, synchrony

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"Make merry by means of music and enforce distinctions by means of ceremony." – Zhuangzi (Yutang, 1941, p. 670).[i]

1. Introduction

People across cultures frequently come together in groups to rhythmically coordinate their bodies with a common beat in *synchrony* (Evans-Pritchard, 1928; Fink et al., 2021; McNeill, 1995; Merker et al., 2009; Savage et al., 2021; Wiltermuth & Heath, 2009). Research finds that synchrony benefits social bonding (Mogan et al., 2017; Tarr et al., 2017), affiliation (Cacioppo et al., 2014; Hove & Risen, 2009; von Zimmerman et al., 2018), group cohesion (Gordon et al., 2020), and trust (Launay et al., 2013; Lang et al., 2017). It may also stimulate prosociality and cooperation, although these effects are less consistent (Atwood et al., 2022; Baier et al., 2021; Cross et al., 2020; Cross et al., 2025; Kokal et al., 2011; Rennung & Göritz, 2016; Tarr et al., 2016; Tarr & Dunbar, 2023; Valdesolo & DeSteno, 2011; Wiltermuth & Heath, 2009).[ii] Meta-analyses show that the bonding effects of synchrony are reliable and small to moderate in size (Mogan et al., 2017; Rennung & Göritz, 2016; Vicaria et al., 2016). At the individual level, positive effects of synchrony include reduced stress (Göritz & Rennung, 2019; although see Dvir et al., 2025) and enhanced pain tolerance, the latter of which indicates activation of the endogenous opioid system (EOS) (Cohen et al., 2010; Tarr et al., 2016; Lang et al., 2017) and stimulation of neural reward centers (Kokal et al., 2011; Chanda & Levitin, 2013). Synchrony also boosts self-esteem (Lumsden et al., 2014). Positive individual effects in turn contribute to social outcomes such as trust (Lang et al., 2017).

Extrapolating from such findings, many researchers argue that synchrony may be an evolutionary adaptation for cooperation and social bonding (Fessler & Holbrook, 2014; Reddish et al., 2013; Merker et al., 2009; Savage et al., 2021; Tarr et al., 2016). In most such accounts, synchrony enhances collectivistic, "groupish," or conservative tendencies, such as cultural tightness and conformism, to solve collective action problems (Gelfand et al., 2020; Haidt et al., 2008; Wiltermuth, 2012; Wiltermuth & Heath, 2009). Importantly, psychological collectivism entails firm hierarchies, ingroup loyalty, and shared norms (Moya, 2022; Talhelm et al., 2014; Triandis, 2001). Evolutionary accounts of synchrony accordingly stress *ingroup* cooperation

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(Savage et al., 2021; Wiltermuth & Heath, 2009) and highlight downsides such as authoritarianism, blind obedience, or ingroup bias (Wiltermuth, 2012; Gelfand et al., 2020).

However, some features of "keeping together in time" (McNeill, 1995) challenge this picture of synchrony as a groupishness maximizer:

1. **Group boundary-breaking** — Synchrony's capacity for bonding and affiliation across, not just within, intergroup boundaries (e.g., Cross et al. 2019; Reddish et al., 2016)
2. **Rapid bonding** — The ability of rhythmic activity to rapidly bond strangers (the "ice-breaker effect") (Pearce et al., 2015)
3. **Leveling/blurring** — Synchrony's tendency to blur roles within the group, potentially hampering interdependent cooperation (e.g., Lang et al., 2016; Wood et al., 2018)
4. **Trance** — The capacity and widespread use of synchrony and rhythmic stimuli for generating absorptive trance states characterized by dissociation and heightened suggestibility (e.g., Campbell, 2023; Dunbar, 2020)
5. **Sanctioning** — The otherwise puzzling fact that cultural authorities frequently disapprove of, or even attempt to ban, expressive, dance-based practices or rituals (e.g., Ehrenreich, 2007; Gioia, 2019).

Collectively, **Features 1-4** depict synchrony as transgressing preexisting group, interpersonal, and even cognitive boundaries (**Figure 1**). Clearly, though, synchrony also forms and strengthens social bonds, including within groups (Launay et al., 2016; Mogan et al., 2017), and it often stimulates an enjoyable sense of unification (Ehrenreich, 2007; Koban et al., 2019; McNeill, 1995). A capacious theory of synchrony would account for these cross-cutting effects, encompassing bonding as well as other, orthogonal or even opposing outcomes within a single explanatory framework. The resulting framework could then inform behavioral, psychological, and evolutionary research on synchrony and adjacent areas of inquiry, including group bonding, the origins of music, and psychology of ritual.

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Figure 1

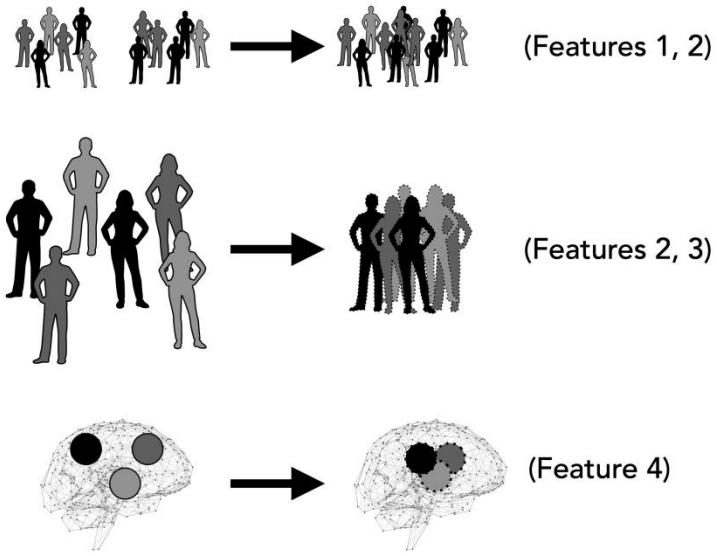


Figure 1 — Synchrony **Features 1-4** relax and blur distinctions at the level of groups, individuals, and cognitive states. Note that **Feature 2**, rapid bonding, overlaps with both group boundary-breaking (**Feature 1**) and leveling and blurring between roles within groups (**Feature 3**).

With this object in mind, in this review I offer a theoretical model of synchrony that extends beyond group cohesion or social bonding. Specifically, I argue that synchrony relaxes top-down social beliefs, such as about who belongs to my group, what roles you and I occupy, and where social boundaries lie.[iii] Once relaxed, these beliefs can be reshaped or revised (Yon, 2021). In other words, synchrony temporarily induces plasticity in the social brain. This plasticity can then expedite new bonds between strangers or renew links between members of a preexisting group (e.g., Dunbar, 2020; Katz, 1982). But it can also melt down and allow revision of higher-level beliefs about the roles and institutions on which people normally rely to navigate and predict

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their social environment (Cross, 2001, 2009; cf. Frith, 2008; Frith & Frith, 2022; Ramstead et al., 2016; Tomasello, 2019; Veissière et al., 2020).

A real-world illustration of this principle is the widespread use of music and dancing at weddings. Marriage in most societies imposes dramatic changes in family networks, with acquisition of new in-laws requiring updates to former beliefs about who "counts as" relatives with whom one shares mutual obligations (Garfinkel, 2018; Kirschner & Tomasello, 2010; Mehr et al., 2019; cf. Searle, 1995). I suggest that group synchrony (as in celebration dances) helps smooth this transition by relaxing now-outdated beliefs and boundaries, prepping the uptake of new ones. This application evokes Turner's (1969) view that many cultural rituals temporarily relax social structure, replacing it with *anti-structure*. Anti-structure facilitates bonding outside the strictures of top-down social categories and so, among other things, eases transitions between social roles.

1.1. Operational Definition

The term "synchrony" is used for many purposes across a sprawling literature. Some researchers use synchrony to refer to simple behavior matching, such as mimicry between mothers and infants (Bernieri et al., 1988). Synchrony may also refer to general convergence of behaviors and attention at medium timescales (hours or days) (Greenfield et al., 2021), or, conversely, the periodic entrainment of low-level physiological or neural processes (Baranowski-Pinto et al., 2022; Bilek et al., 2022; Wheatley et al., 2012). Entrained affective processes have also been described as synchrony (Páez et al., 2015; Vanutelli et al., 2017). In clinical literature, synchrony refers to spontaneous client-therapist motor alignment, such as mirroring body postures or vocal pitch (Koole & Tschacher, 2016). Finally, in rhythmic sensorimotor interactions, synchrony may mean spontaneous, transient synchronization between persons (Ayache et al., 2021; Tschacher et al., 2018) or intentional synchronization to a shared (usually audiomotor) beat (Cross et al., 2025; Wiltermuth & Heath, 2009).

It is the last of these definitions — rhythmic audiomotor entrainment — that I wish to highlight. Specifically, for our purposes I define synchrony as *interpersonal sensorimotor entrainment to a*

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shared, isochronous auditory beat with intervals of under 2 seconds.[iv] This definition points to an ideal type. However, much of the research surveyed below uses paradigms that meet only some of this definition's criteria. Some studies manipulate synchrony as synchronized walking or chair rocking without auditory stimulus (e.g., Atherton et al., 2019; Richardson et al., 2012). Others investigate synchronized tapping using computerized metronomes and so lack a non-simulated interpersonal dimension (e.g., Cacioppo et al., 2014; cf. Repp, 2005; Repp & Su, 2013). Others, again, focus on spontaneous (largely non-rhythmic) synchronized alignment of movements or movement timing (e.g., Fusaroli & Tylén, 2016; Wallot et al., 2016). Group sizes vary as well. While numerous studies feature large synchronized groups (e.g., Pearce et al., 2017), including with virtual partners (e.g., Biswas & Brass, 2024), many others are limited to dyads (e.g., Lang et al., 2017). Nevertheless, as we will see, these apparently different paradigms tend to elicit similar effects overall — particularly boundary-breaking, bonding, and leveling (**Features 1-3**). This tendency suggests that similar social and cognitive processes are at work across paradigms. Thus, many of the effects surveyed below should result from different varieties of real-world synchrony, from simple clapping in time in !Kung trance dancing (Campbell, 2023) to complex West African drumming (Jacoby et al., 2021) or Western orchestral performances and choral singing (Hilt et al., 2019; Pearce et al., 2017).

Supporting this idea, blurred representations of self and other are elicited during dyadic, group, auditory, and visual synchronization paradigms alike (Biswas & Brass, 2024; Fujiwara et al., 2023; Paladino et al., 2010; Reddish et al., 2020). Koban et al. (2017) explain this effect as the result of predictive streamlining in the brain; in their account, rhythmic synchronization in any sensory modality minimizes the representational differences between oneself and others, leading to reduced processing demands for predicting social behavior. Essentially, all forms of synchrony reduce processing costs for social prediction on short timescales, but audiomotor synchronization distills and heightens this effect. This preference for audiomotor synchronization reflects the fact that auditory processing is involved for human beat perception of *all* sensory rhythms, even visual ones (Chauvigné et al., 2019). Thus, audiomotor beat-tracking processes are activated for human subjects across most or all studies surveyed below, and audiomotor prediction is close to the core of the phenomenon we wish to describe.

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Although synchrony is a form of joint action, with multiple agents coordinating in service of a shared goal (namely, to stay in time with a shared beat) (Kirschner & Tomasello, 2010), this unique profile thus distinguishes it from other types of joint action (Dale et al., 2013; Knoblich & Sebanz, 2008). Specifically, the joint goals in synchrony are more immediate and less abstract, motor actions are more convergent, and social representations are less differentiated and complex. We might imagine a dashboard of sliders that control variables such as goal complexity, timeframe, and sensorimotor convergence. As we push more sliders toward simple coordination goals, short timeframes, and convergent (less differentiated) actions, we more and more closely approach audiomotor synchrony, as opposed to, say, a workplace collaboration with a deadline next week.[v] That is, synchrony is a special form of joint action whose timeframe is immediate and which collapses differentiated roles.

1.1.2. A Note on Scope

This review aims to contribute to theoretical and empirical discussions of synchrony in the social and cognitive sciences. Although it engages with research in biomusicology, it concerns music only to the extent that music entails synchrony. The reader should therefore be careful not to gloss synchrony as "music" below, since not all forms of music are based on the isochronic pulse needed for synchronization, and not all forms of synchrony are musical (e.g., cadence marching without accompaniment) (McNeill, 1995; Mehr et al., 2019; Savage et al., 2015). Neither am I offering a fleshed-out evolutionary argument for the origins of human synchrony, although Section 7 briefly addresses this question. I am instead offering a theoretical model that I believe captures a greater swathe of synchrony's actual effects than any alternative account. Importantly, then, the model does not stand or fall with any particular evolutionary story. Whether traits for synchrony result from adaptive selection for group cohesion (Mehr et al., 2021; Savage et al., 2021) or some other function (Harvey, 2018), or are simply functionless byproducts (e.g., Pinker, 2009), synchrony equally generates **Features 1-4** and evokes **Feature 5**.

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1.2. Overview: Synchrony's Plasticity-Inducing Effects

Let us now survey the evidence for **Features 1**-**4** of synchrony, beginning with **Feature 1** (group boundary-breaking). In one study, synchrony forged bonds across minimal group boundaries with outgroup members (Tunçgenç and Cohen, 2016). Similarly, Miles et al. (2011) reported that spontaneous synchrony was more prominent *across* than within minimal groups, suggesting that participants implicitly used synchrony to try to establish new social connections rather than shoring up existing ones. It is thus unsurprising that synchrony has been found to predict cooperation among participants from different nationalities better than those from the same country (Cross et al. 2019) and to reduce ethnic stereotyping (Atherton et al., 2019; Cross, Nixon, Smith, et al., 2025). In another pair of studies, group synchrony led participants to act more helpfully toward distant outgroups (Reddish et al., 2014) and outgroup individuals (Reddish et al., 2016). Importantly, prosociality in these studies extended beyond performers to include those who had not performed in synchrony or who were not physically present. In Reddish et al. (2016), synchrony participants also failed to show greater identity fusion with a salient larger group (their university) than participants in the asynchrony condition. Prosocial effects were therefore generalized rather than limited to an extended ingroup, and synchrony failed to strengthen an established group boundary. Relatedly, Pearce et al. (2016) found that choral singing (which requires rhythmic synchrony; Delius & Müller, 2022) boosted feelings of closeness with outgroup singers in both cooperative and competitive conditions, whereas competitive singing reduced subjective closeness within ingroups. The authors concluded that musical coordination was particularly effective for increasing social closeness with unfamiliar others. Supporting this inference, Fujiwara et al. (2020) found that spontaneous interpersonal synchronization between subjects at low periodic frequencies (slower than musical tempos) indicated established social rapport, but synchronization at higher frequencies (close to 1 Hz, near the optimum for musical synchronization [Repp, 2005]) indicated a motivation to bond with strangers.

These findings point to **Feature 2** (rapid bonding). In Pearce et al. (2015), unacquainted subjects randomly assigned to a choral singing group bonded much more quickly over the beginning of a 7-month timeframe than subjects assigned to crafts or creative writing classes. Bolstering this

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result, in a large global study (Savage, in press), preliminary analyses (n = 165) reveal stronger bonding effects for group singing than for speaking. Shared rhythm may thus exert an "ice-breaker effect" (Launay, 2015; Pearce et al., 2017), generating social bonds particularly rapidly compared with other forms of social interaction. The ice-breaker effect implies that synchrony is uniquely efficient at rapidly forging new subjective ingroups orthogonally to established ones (Cross, Turgeon, & Atherton, 2019).

Synchrony should boost performance in all kinds of group tasks if it were primarily a solution to collective action problems. However, at the intragroup level, Lang et al. (2016) found that synchrony reduced dyads 'improvement over time on a motor task requiring different roles, suggesting that latent sensorimotor coupling between subjects interfered with interdependent role-taking (cf. Trapp et al., 2020) (**Feature 3**, blurring and leveling). Similarly, Wood et al. (2018) found that synchrony was associated with poorer coordination and worse outcomes on a group collaboration task that called for leadership distinctions (Ronay et al., 2012). Synchrony also predicted less group cohesion and subjective similarity, possibly reflecting frustration with poor task outcomes. Analogously, several studies have reported that spontaneous synchronization during joint action predicts worse outcomes when interdependent rather than identical roles are needed (Abney et al., 2015; Fusaroli and Tylén, 2016; Wallot et al., 2016). Given that excessive homogeneity within groups can impair decision-making (Baumeister et al., 2016; Mahmoodi et al., 2015; Ronay et al., 2012; Tiedens et al., 2007), these findings may reflect a tendency for synchrony to interfere with divergent or interdependent role-taking and leadership (although see Miles et al., 2017).[vi] Supporting this inference, Kempf, Benedek, et al. (2024) found that synchrony-enhanced social cohesion reduced creativity in subsequent musical interactions. This characterization dovetails with widespread reports of interpersonal blurring during synchrony (Cross et al., 2021; Kempf, Maes, et al., 2024; Tarr et al., 2014).

Finally, rhythmic synchrony and dance are frequently used to elicit trance, such as during ecstatic religious practices (Bourguignon, 1976; Campbell, 2023; Dunbar, 2020; Garfinkel, 2018; Gosseries et al., 2024; Huels et al., 2021; Rouget, 1985; Richter & Ostovar, 2016; Winkelman, 2015) (**Feature 4**). Rhythm-induced trance often involves the loss of a bounded sense of self (Schäfer & Kreuzberg, 2023) and reduced awareness of external surroundings (Hove et al.,

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2016). Some phenomenological and behavioral effects of trance mirror those of psychedelics (Huels et al., 2021; Newson et al., 2021; Winkelman, 2017). Because rhythm-induced trance involves cognitive and perceptual decoupling from one's surroundings (Hove et al., 2016; St John, 2006), its utility for social bonding, joint action, or coalition signaling is narrow (although see Frecska & Kulcsar, 1989).

1.2.1. Critiques and Limitations in Synchrony Research

Not all conclusions in synchrony research are equally robust. In a meta-analysis, Atwood et al. (2022) found evidence that the synchrony-prosociality link was an artifact of experimenter and (or) participant expectations (see also Rennung & Göritz, 2016). Of course, expectancy effects might reflect accurate intuitions about genuine prosocial effects of synchrony (Tunçgenç et al., 2023). Even infants seem to expect synchrony to motivate prosociality and affiliation (Fawcett & Tunçgenç, 2017), suggesting that interpretations of synchrony as a signal or cue of cohesion may be partially innate. However, even if expectancy effects invalidate prosociality findings, synchrony's effects on bonding and affiliation remain well supported. For instance, in another meta-analysis, Rennung & Göritz (2016) found reliable effects and moderate effect sizes in blinded experiments for prosocial *attitudes* but not *behaviors*. Similarly, in a study that controlled for expectancy effects, Tarr et al. (2018) found that synchrony with a virtual reality (VR) partner increased social closeness and self-other overlap, but not willingness to help others or be helped by them. In another VR experiment, Cross, Nixon, Smith, et al. (2025) likewise reported that synchrony predicted affiliation but not prosociality. Finally, in Cross, Pares, Gali, et al. (2025), children preferred more spontaneous physical closeness after musical synchrony, but acted more prosocially in an economic game only after *non*-musical (visual) synchrony. Synchrony is, then, overall more robustly associated with social bonding and affiliation than with prosocial cooperation or altruism (Tarr et al., 2023).

A useful interpretation of these findings is that audiomotor synchrony has separable effects on top-down social cognition versus affective social boundaries. Cross, Pares, Gali, et al. (2025) argued that synchrony without an auditory beat required participants to focus more on one another and so enhanced top-down prosocial decision-making. By contrast, musical synchrony

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captured participants' affective attention bottom-up, directing cognitive resources away from abstract norms about sharing. Such relaxation does not necessarily entail cooperation, since cooperative obligations emerge from joint-intentional relationships with defined roles and robust top-down control (Tomasello, 2019).[vii] This interpretation thus converges with the view that synchrony relaxes top-down social constraints and boundaries.

During synchrony, then, social doors are opened, hierarchies flattened, and cognitive maps wiped clean and redrawn. In turn, I suggest that the resulting multilevel loosening of boundaries described in **Features 1-4** helps to explain **Feature 5** (sanctioning), because leaders and authorities want strong hierarchies and effective structures to coordinate group action. Synchrony can interfere with this by relaxing inhibitions needed to fulfill collaborative roles and undermining hierarchies. Authorities are therefore often more ambivalent toward synchrony-enabling activities such as expressive music and dance than we would expect if these activities simply encouraged cooperation and obedience. Instead, authorities have frequently outright condemned such activities (Wagner, 1997).

1.3. Predictive Processing and Plasticity

In what follows, I aim to explain, mechanistically, how rhythmic synchrony induces plasticity and so elicits **Features 1-5**. To do so, I will rely on the framework of hierarchical Bayesian predictive processing, which portrays the brain as predicting sensory input and updating internal models in a continuous cycle of perception and error correction (Friston, 2010; Clark, 2013; Yon, 2021). For humans, *social prediction*, or anticipating each other's behavior, is a particularly important problem to solve (Brown & Brüne, 2012; Ma et al., 2024; Tamir & Thornton, 2021). Rhythmic synchrony greatly aids social prediction at the sensory and sensorimotor levels (Comstock & Balasubramaniam, 2018; Jacoby et al., 2021; Koelsch et al., 2019; Levitin et al., 2018; Proksch et al., 2020). These levels entail short timescales and rapid fluctuations in inputs and outputs, whereas higher-level cognitive functions implicate longer timescales for planning and processing (Clark, 2013; Friston et al., 2017; Kiebel et al., 2008; Sánchez et al., 2021).

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In hierarchical predictive processing, more salient low-level sensory inputs (for example, the sound and sensation of clapping to a predictable beat) make higher-level models and beliefs less salient, relaxing them and so facilitating belief updating (Bottemanne, 2024; Hohwy, 2012; Yon, 2021). At a neurobiological level, then, synchrony facilitates relaxation and revision of top-down beliefs (priors) by increasing the salience of bottom-up interpersonal signals through predictable, temporally fine-grained rhythmic coordination. This process sharply distinguishes synchrony from other forms of coordination and joint action that demand top-down planning and abstract representations of different roles and shared objectives (Sartori & Betti, 2015). The basic mechanistic argument of this review, then, is that synchrony temporarily weakens or relaxes top-down social beliefs by reducing social prediction to a temporally fine-grained sensorimotor process of mutual rhythmic entrainment. We can call this the *relaxed priors through synchrony* (RePS) model.

The paper is structured as follows. Section 2 provides an overview of predictive processing for social coordination in complex joint action, which entails extended spatiotemporal scales and "top-heavy"control for joint regulation (cf. Carhart-Harris & Friston, 2019). This section will use the example of a team of workers collaborating to achieve a shared, deferred goal, which will link the subsequent sections. Section 3 surveys the mechanisms by which synchrony relaxes this top-heaviness, reduces relevant timescales to the short intervals between beats, and introduces flexibility in social processing, thereby laying the foundations for **Features 1-3** (boundary-breaking, rapid bonding, and leveling/blurring). Section 4 extends this mechanistic discussion to explain how relaxed top-down social beliefs are subsequently revised and how synchrony results in trance at extremes (**Feature 4**). Section 5 applies this mechanistic story to explain why, in contrast to rituals that demand top-down self-regulation and impose social boundaries, authorities sometimes discourage or ban expressive music and synchrony (**Feature 5**). Section 6 discusses empirical predictions of the RePS model for future research at the neurobiological, psychological, and cross-cultural levels, and Section 7 concludes with evolutionary implications, responses to potential critiques, and summary.

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2. Social Predictive Processing: Guessing What We Are Going to Do

Researchers increasingly understand synchrony, music, and rhythm in terms of predictive processing (Koban et al., 2019; Koelsch et al., 2019; Proksch et al., 2020; Pöppel et al., 2022; Vuust et al., 2022). Predictive processing theories were originally developed to explain basic perception and action but have increasingly been applied to higher-level functions, including social and cultural cognition (Frith & Frith, 2022; Ramstead et al., 2016; Theriault et al., 2021; Veissière et al., 2020; Winkler et al., 2009; Wolpert & Flanagan, 2001). These theories posit that the brain works to minimize prediction error, or the mismatch between internal hierarchical generative models and sensory inputs (Allen & Friston, 2018; Clark, 2013; Yon & Frith, 2021). The brain "guesses" at the (hidden or inferred) causes of incoming evidence at each hierarchical level, then progressively seeks to reduce discrepancies between these guesses and evidence from the preceding lower level. Guesses are instantiated as models or Bayesian prior beliefs that evolve through inference from statistical regularities in external events; priors make downward predictions, and (sensory) evidence feeds upward to inform updates to priors (Keller & Mrsic-Flogel, 2018; Frith & Yon, 2021; Yon, 2021). Downward predictions gate or filter incoming evidence by attenuating strongly predicted events; thus, only prediction error is passed upward, allowing the brain to "compress" incoming information (Clark, 2013). Perception and cognition hence operate as a bidirectional cascade of bottom-up inputs and top-down predictions that iteratively and efficiently work to improve the brain's grasp on the world (Clark, 2013; Gordon et al., 2019; Hohwy, 2012).[viii]

Whether we are dancing with others or forecasting the weather, accurately predicting our experiences is thus a central motivator for cognition and behavior that elicits powerful neurohormonal rewards (Allen & Friston, 2018; Hesp et al., 2021; Miller et al., 2020; Salimpoor et al., 2015). That is, we feel good when our predictions come true. One way to make this happen is to update our priors in line with incoming evidence. However, the brain can also direct the motor system to bring evidence in line with predictions using *active inference* (Allen & Friston, 2018; Friston, 2010). In active inference, motor actions result from counterfactual predictions that are self-fulfilled by carrying out the action (Friston, 2010; Brown et al., 2011; Yon & Frith, 2021). Predictive processing thus encompasses not only correcting top-down models of the world, but also using predictions to guide behavior and alter our surroundings (Pezzulo et al., 2021).[ix]

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2.1. Precision Modulates Predictions

Signals propagating through the hierarchy are modulated by confidence or *precision* (Hohwy, 2012; Kanai et al., 2015; Limanowski et al., 2024; Yon & Frith, 2021). For example, imagine Susan, a baker preparing to cater a large wedding. She expects her assistants to arrive for work as scheduled. The first-order content of this prediction is "my assistants will be on time for their morning shift." The second-order precision of this prediction reflects how confident Susan is that this will actually happen. Signals with a narrower statistical range are more precise (Friston, 2024). If traffic is bad today, the precision of Susan's prediction may be lower, reflecting a wider range of possible arrival times.

How priors and their precision are neurobiologically instantiated is still incompletely understood (Mikulasch et al., 2023; Walsh et al., 2020). However, evidence indicates that deep-layer pyramidal neurons play an outsized role in propagating top-down (backprojection) inputs to inform perception (Rolls, 2021). Precision for high-level models is thus thought to correspond to activation patterns for deep-layer pyramidal neurons in the cortex, with greater synchronization between neurons representing stronger (more precise) top-down expectations (Asilador & Llano, 2021; Kanai et al., 2015). Thus, if Susan is pretty sure everyone will show up on time, activity in the deep-layer neural units representing that prediction is highly synchronized. If she is less confident about this (because, say, she knows traffic is bad), activity in those units will be more dispersed and noisy, corresponding to a broader spread of anticipated arrival times. As we will see below (Section 4.1), priors can thus be understood as attractor basins in an energy landscape, with coherence among neural units corresponding to deep, hard-to-escape basins and imprecision corresponding to shallower basins (Hohwy, 2012).

2.1.1. Predictive Pistons: Top-down vs. Bottom-up

Precision also modulates feedforward (sensory) evidence. Some sensory stimuli are coded as highly precise, while others are not. As Susan opens the bakery and flicks on the light, the sudden illumination from a bright fluorescent bulb delivers a precise sensory signal, but a storeroom vapor lamp that warms up slowly elicits a more imprecise one. When a precise,

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attention-grabbing sensory signal enters the hierarchy, it renders higher-level neural units more receptive to this new evidence, so that top-down and bottom-up precision are inversely related (Bottemanne, 2024; Feldman & Friston, 2010; Yon et al., 2019). This tradeoff can be understood in terms of salience and attention. Susan's prior belief that the storeroom will eventually become brightly lit is, at first, more precise than the noisy, ambiguous evidence emanating from the vapor lamp. Her priors are more salient than the evidence, so her attention is top-down (Kanai et al., 2015; Katsuki & Constantinidis 2014). In general, when sensory evidence is noisy, we fall back on top-down models to help us make sense of the ambiguity, whereas precise sensory signals capture our attention bottom-up, letting us relax our models (Feldman & Friston, 2010; Hohwy, 2012; Katsuki & Constantinidis 2014; Yon & Frith, 2021).

Brain oscillations appear to track these shifts, with low-frequency (primarily alpha, also beta) frequencies reflecting stronger top-down predictions and inhibited bottom-up flow, whereas higher (gamma) frequencies are associated with bottom-up attention (Bastos et al., 2020; Bauer et al., 2014; Dahl et al., 2022; Mayer et al., 2016; Schroeder & Lakatos, 2009). Noradrenaline, which has a complex modulatory relationship with gamma, also boosts the gain on bottom-up signals (Section 3) (Cape & Jones, 1998; Marzo et al., 2014; Neves et al., 2018). If a rush of late-morning customers streams in when the shop is usually quiet, Susan's brain thus releases noradrenaline and boosts gamma to motivate action and relax her prior "the shop is always quiet at 10:00 am."

2.2. The Top of the Hierarchy Is Talk

Different levels of the processing hierarchy target different scopes of experience (Clark, 2013; Frith, 2023; Kiebel et al., 2008; Raut et al., 2020; Yon & Frith, 2021). Low- and intermediate-level predictive models focus on immediate sensory and sensorimotor data ("If I flip this switch, the light will come on"), whereas higher levels target broader, more abstract predictions ("If I fulfill the order tomorrow, the customer will be happy and recommend me to other clients") (Friston, 2017; Pezzulo et al., 2021). Higher levels of the predictive hierarchy update and integrate information at large temporal scales, whereas the lowest sensory layers update at millisecond intervals (Basgol et al., 2024; Clark, 2013; Friston et al., 2017; Hasson et al., 2008;

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Zacks, 2020). The lowest predictive models are thus unimodal sensory priors instantiated in sensory cortices; intermediate or "empirical" sensorimotor and multimodal priors are instantiated in mid-level cortical and motor regions and the hippocampus; and the highest-level, most abstract priors are instantiated in deep-layer cortical regions, such as Level 5 pyramidal neurons in the default mode network (DMN) (Kok & Turk-Browne, 2018; Luo et al., 2024; Menon, 2023). Neurobiologically, then, abstract representations of all kinds are instantiated at higher levels of the cortical hierarchy with sparser architectures and are thus coarser grained, both in terms of content and temporal scope, than more concrete representations (Gilead et al., 2020).

The hierarchical structure of predictive processing thus dovetails with construal level theory, which specifies that mental representations vary along a continuum of psychological "distance" or concreteness to abstraction, with more abstract representations standing at greater remove from the self along temporal, spatial, social, and hypothetical dimensions (Gilead et al., 2020; Liberman & Trope, 2008; Trope & Liberman, 2010). For example, an event scheduled for tomorrow would evoke more abstract representations than one imminently about to begin, because the former is both more temporally distant and more hypothetical (less certain to take place) than the latter (Bausenhart et al., 2023; Stillman et al., 2017). People construe socially distant others at a higher level of abstraction than close others (Stephan et al., 2011). Additionally, high-construal beliefs broadly address abstract *why* questions (offering general goals or principles for shared action) instead of granular *what* or *how* questions (the means to achieve goals or identification of low-level stimuli) (Baetens et al., 2014).

Notably, lower- and intermediate-level priors are largely shaped by statistical inferences from sensory evidence, but high-level social priors are predominately shaped by symbolic communication and interactions with others (Gilead et al., 2020; Frith, 2023; Rossignac-Milon et al., 2020; Yan et al., 2023). For example, say that news reports and customers who work in finance agree that a recession is likely this summer. Susan now expects reduced customer traffic in a few months. This is a fairly abstract prior with high-construal content. It was not integrated directly from multimodal sensory input, but conveyed directly to the top of the hierarchy using symbols (Roepstorff & Frith, 2004). Later, sampling bottom-up sensory evidence (shorter lines of customers at the till, reduced volume of background chatter in the shop) may reinforce or

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update this prior, but further news reports and conversations with knowledgeable customers will continue to play a role as well. Top-down input is important in forming abstract beliefs because estimating precision is difficult for predictions that concern very broad statistical regularities (Frith, 2023). We need conceptual input from others to fill in our knowledge gaps.

High-level beliefs and high construal are thus tightly interlinked with symbolic communication, implicating complex social cognition and metacognition (Frith, 2023; Gilead et al., 2020; Ma et al., 2024; Sacheli et al., 2022). Such higher-order mentalizing, including tracking others 'abstract beliefs, is energetically demanding, suggesting a kind of metabolic top-heaviness in the social brain (Pa et al., 2017). However, the complexity of knowledge we need for successful social prediction varies by context. During simple nonverbal interactions (such as synchrony), we can easily predict behavior using low-level sensorimotor models without conceptual content (Sacheli et al., 2022). These models largely rely on online sensorimotor simulation to understand others' point of view in an embodied way (Gilead et al., 2020; Sebanz & Knoblich, 2009). But in more complex interactions, we draw on theory-based knowledge instantiated in higher-level priors, including about conventions and institutions that coordinate behavior and shape mutual normative expectations over longer terms (Friston et al., 2024; Pöppel et al. 2022; Ramstead et al., 2016; Veissière et al., 2020).

2.3. Complementary Roles and Self-Control in Joint Action

The role of institutions and conventional norms in social prediction highlights an important fact: social cognition is rarely about just predicting what others do, but rather interacting with others to achieve shared aims (Siposova & Carpenter, 2019; Vesper et al., 2017). These joint actions are psychologically triadic, encompassing at least two minds that recursively track each other's attention in relation to an object or goal (Saxe, 2006). This amounts to joint intentionality (Tomasello et al., 2005). For example, Susan and an assistant haul ingredients from the cooler, one finding the items, the other reading from a list. They jointly intend to gather the ingredients for a cake, minimizing prediction error by tracking one another's roles, intentions, and actions and coordinating to accomplish the mission (Friston et al., 2024; Pöppel et al., 2022). As in most complex joint action, they play different parts, Susan leading and the assistant following (Ronay

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et al., 2012; Sartori & Betti 2015; Van Vugt & Ronay, 2014). (Note the contrast with synchrony **Feature 3**, leveling and blurring of roles.)

In keeping with the structure of nested priors, both participants represent these goals hierarchically, with more abstract, higher-level goals constraining concrete and subordinate tasks (Cellier et al., 2022). High-level goals implicate longer timeframes, more nested sub-goals, and incentives and consequences that may be deferred by longer periods (Gordon et al., 2023; Kourtis et al., 2019; Knoblich & Sebanz, 2008; Le Bars et al., 2022; Roepstorff & Frith, 2004). The very high-level prior "I am a bakery manager" thus makes downward predictions about how Susan might generally play her part, but lower levels progressively instantiate narrower priors for implementing sub-goals via active inference: "Bakery managers run the shop"; "running the shop meaning baking wedding cakes"; "for baking, I tell assistants which ingredients to fetch"; "I must read now from this list." At the lowest layers are sensory predictions beyond the scope of joint regulation: "The air will feel brisk in the cooler."

Because higher-level joint goals promise (often greatly) delayed rewards, they demand lots of inhibitory self-control to orchestrate these nested priorities (Fujita et al., 2025; Stephan et al., 2010; Tomasello, 2019). The relevant incentives are deferred and high construal. Susan expects that her assistants will follow directions because both she and they recognize that persistently flouting her orders could get them fired, triggering negative personal and financial downstream consequences (Constant et al., 2019; Theriault et al., 2021). Similarly, maybe Susan wants a long coffee break, but too bad: she is needed in the kitchen, so she slurps her coffee quickly and hurries back. Everyone's roles in the bakery are" desire-independent" (Searle, 1995).[x]

Importantly, specialized goals at lower levels entail that, although everyone's actions are coordinated overall, their separate motor actions are often spatially and temporally independent. Working side-by-side, Susan and the assistants pursue different action plans for their various tasks, balancing high-level coordination against low-level sensorimotor segregation (Hasson & Frith, 2016) (again, contrast synchrony **Feature 3**). This segregation of sub-tasks is complicated, however, by the fact that humans tend to automatically track and mimic each other's behavior (Belot et al., 2013; Chartrand & Bargh, 1999; Sartori & Betti, 2015). Susan and the assistants

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must therefore exert *self-other control* to suppress automatic imitation so they can perform their distinct roles without accidentally mirroring each other (Dale et al., 2013; Semin & Cacioppo, 2008; Sowden & Shaw, 2014). This self-other segregation represents an additional layer of inhibitory control for complex joint action.

2.3.1. The Accuracy-Simplicity Tradeoff

Finally, it matters *when* the assistants do what Susan asks, not just whether they do it. That is, timing and temporal processing are particularly important for social prediction (Hari & Parkkonen, 2015; Schirmer et al., 2016). Yet as we have seen, the higher-level social priors that scaffold complex interactions are temporally coarse grained and implicate long time horizons. These priors thus provide scope for anticipating events at the scale of minutes, hours, and days, but — crucially — *not at the sensorimotor scale of seconds and milliseconds*. The belief that bakery assistants are supposed to help bake cakes cannot predict the exact moment an assistant will duck around the shelves to fetch the sugar. As a result, many realtime actions in the bakery remain comparatively noisy, generating a stream of granular sensory prediction error. Everyone accepts this noisiness because it is the price of a tradeoff between model accuracy and simplicity (Tschantz et al., 2020; Wauthier 2022). The brain is a "cognitive miser" that uses shortcuts and heuristics whenever possible (Fiske & Taylor, 1991; Wheatley et al., 2012). High-level normative priors, such as "this person is a baker's assistant and I am a baker," thus streamline social prediction in broad strokes at the cost of allowing for abundant low-level noise. High-precision social priors do not directly "explain away" this uninformative noise, but rather ensure that the resultant prediction error signals are low precision and hence not salient. Reciprocally, the granular noisiness further tightens precision on the priors. Susan and her assistants wind up relying extensively on top-down attention while at work.

This makes work interactions very unlike synchrony, in which participants predict and respond to precisely timed (subsecond) rhythmic movements with low levels of sensorimotor noise (Koelsch et al., 2019; Repp, 2005; Vuust et al, 2022). Social prediction at the bakery, then, is a high-dimensional affair. It demands effortful self-regulation, long time horizons, and high-level construal. Susan is both a physical person and an abstract role. Yet to the extent that the joint

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goal is salient, Susan and the assistants see each other as high-construal roles first and persons second, requiring top-down attention and self-other control (Tiedens et al., 2007). Working together, they end up in a persistently "top-heavy" cognitive mode characterized by strong normative priors and restricted sensory sampling. Predicting the social environment means playing a jointly regulated role and counting on others to play theirs.

2.4. The Top-Heavy Social Brain

This everyday top-heaviness scales up to account for stability in categorical social beliefs, such as about bounded cultural groups, which tend to be salient across contexts (Balliet et al., 2014; Kunovich & Hodson, 1999; Over, 2018). Stereotypes about outgroups are an example of such durable high-level social beliefs (Gelpí et al., 2025). Susan's work team might initially struggle to integrate a new employee from an unfamiliar cultural background they perceive as foreign or untrustworthy, and which they accordingly represent at a high construal level (Li & Hills, 2021). Reinforcing this social distance, the hypothetical new employee may lack the common knowledge, or mutually compatible normative priors, to support complex joint action in their workplace (contrast synchrony **Feature 1**, boundary-breaking) (Siposova & Carpenter, 2019). The unfamiliar habits of the new employee and resultant challenges in working together could slow bonding between teammates (contrast synchrony **Feature 2**, rapid bonding).

Top-heavy social cognition thus implies social restrictiveness. Only people who share compatible high-level priors can coordinate for complex, temporally extended tasks. These priors, shaped largely by symbolic communiqués, are not equally held by anyone. We need a shared body of ideas, which implies common language and cultural context. Because much of daily life involves working with others to accomplish long-range tasks, these social boundaries tend to dominate in the workaday world, along with the associated status hierarchies and behavioral self-control they imply. Turner (1967) calls this state "structure."

Importantly, because high-level priors are distant from the sensory layer of the processing hierarchy, they tend to be "sticky" in the face of contradictory bottom-up evidence, whereas lower-level priors are more malleable (Frith, 2023; Friston et al., 2017; Hohwy, 2012; Kiebel et

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al., 2008; Yon 2021). High precision also makes priors more resistant to updating, so that relaxing their precision is tantamount to making them easier to revise (Behrens et al., 2007; Bottemanne, 2024; Frith, 2023). Top-heavy processing and persistently high precision for coarse-grained social priors therefore mean that these priors often resist updating.[xi] For example, the belief that Group X is alien to our Group Y may be subject to a kind of hysteresis or stickiness, so that changing it requires a stronger stimulus than originally led us to form it (McGovern & Otten, 2024; cf. Bourdieu, 1990; Strand & Lizardo, 2016). Nevertheless, social priors sometimes must be updated. Our extant models might be overfitted, unable to generalize to new settings (cf. Hoel, 2021). Roles shift, groups merge or make peace, and new circumstances challenge our cultural schemata. Our responsibilities and joint self-regulation need to adapt accordingly. We thus face a conundrum: given the top-heaviness of everyday social cognition, how do we change our high-level social priors when needed?

2.4.1. Inefficient and Unreliable Ways to Change Your Mind

Consider the prior belief that a certain outgroup is untrustworthy. One way to relax this prior (that is, make it less precise) could be to spend extended time with members of this outgroup, in line with the contact hypothesis for weakening stereotypes (Allport, 1979; Zhou et al., 2019). Many individual positive or neutral encounters might gradually loosen the precision of the belief "those guys are strange and distant." This strategy would likely be effective, but potentially time-consuming and inefficient. A more efficient but less certain way of changing high-level beliefs might be simply to transmit the new information verbally, going straight for the top of the processing hierarchy. For example, in trust games with VPs, verbal information from experimenters (e.g., "this player is trustworthy") overrides bottom-up evidence (e.g., defection by the VP) so that prediction errors no longer trigger the striatum activity that would otherwise indicate reward learning (Fouragnan et al., 2013). In other words, the experimenter has directly loosened the precision of incoming evidence and tightened the precision of the prior model (Frith, 2023). Thus, if I tell you "Group X members are trustworthy," you might update your beliefs and act accordingly. But this will probably only work if you trust me, your prejudices are not too deeply ingrained, and I do not come across as manipulating you (Pettigrew, 1998). If these conditions are not met, you might respond with psychological reactance and rigidify your

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anti-outgroup priors (Li & Shi, 2026). Additionally, if our incentives are not aligned (for example, because we are competing for resources, or I myself am a Group X member), you may resist my attempts to change your mind. Indeed, even if all the conditions are met, verbal or authoritative messaging may still not succeed in altering your view of the outgroup (Murrar & Brauer, 2019). Priors about high-stakes questions such as status, group identity, and boundaries will therefore tend to be sticky against both bottom-up evidence and top-down social communiqués except in narrow contexts.

Maybe we could use blunter instruments, then. Psychedelics have been argued to globally relax the precision of high-level priors, freeing bottom-up information to propagate more easily throughout the cortical hierarchy (Carhart-Harris & Friston, 2019; Singleton et al., 2022). Accordingly, in Roseman et al. (2021), ayahuasca ceremonies quickly increased social bonds between Israelis and Palestinians. Alcohol is also associated with rapid social bonding (Sayette et al., 2012; Dunbar et al., 2017), short-timescale processing (Fairbairn & Sayette, 2013), and behavioral disinhibition (McPhee & Hendershot, 2023). Plausibly, these effects might suggest relaxation of normative priors and their associated top-down constraints. However, people who are drunk or tripping frequently behave in unpredictable and erratic ways. This blunt strategy for relaxing priors increases overall social prediction error. Can we directly relax our social priors without undermining social prediction?

3. Synchrony and Plasticity in the Predictive Brain

Imagine that the wedding has now arrived. Susan's bakery team has delivered the cake to appreciative clients, who happen to be relatives of Susan's and have invited the them to remain for the reception. Eating dinner, Susan perceives that the bride's family (her new in-laws) are dressed differently and speak with distinct accents. They represent a cultural outgroup. Together, she and they do not yet constitute a "we," so the wedding celebration is not reinforcing a preexisting group. By default, then, Susan initially processes these guests as socially distant, perhaps activating coarse-grained schemas and stereotypes (McGovern & Otten, 2024). Yet after dinner, when she joins both families on the dance floor, she feels the perceived boundaries between the groups dissolve in a shared enjoyable experience, even as the conventional

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boundaries between herself and her assistants also relax (synchrony **Features 1-3**). Here we have an intervention that seems to loosen Susan's high-level priors quickly, in a shared context of disinhibited fun, but without sacrificing social predictability. In fact, it enhances and streamlines it (Koban et al., 2019). How does synchrony enable this unique combination?

3.1. How Synchrony Works

3.1.1. Beat Perception and Reward

Answering this question requires (appropriately enough) drilling down to lower-level brain and cognitive mechanisms. It begins with rhythm. As the music begins to play, Susan's brain recruits motor planning networks that are also involved in estimating granular time intervals (Bengtsson et al., 2009; Cannon & Patel, 2021; Comstock et al., 2018; Grahn & Rowe, 2013; Levitin et al. 2018; Merchant et al., 2018; Patel & Iversen, 2014). Rich interconnections between the auditory system and motor and reward regions generate tacit motor pulses that internally recapitulate the rhythm and meter, grounding the subjective experience of the beat in entrained neural firing patterns (Cannon & Patel, 2021; Grahn & Rowe, 2013; Levitin et al., 2018; Tal et al., 2017). This "neural resonance" is thought to amount to a predictive sensorimotor model that trains Susan's attention to the rhythmic on-beats (Large et al., 2015; Zoefel et al., 2018).[xii] As this is going on, the brain's timing networks become co-activated with reward areas in the striatum, suggesting that predictive timing and dopamine-mediated rewards are reciprocally reinforcing one another (Chanda & Levitin, 2013; Hoehl et al., 2020; Matthews et al., 2020). Both beta-wavelength cortical rhythms, implicated in motor control, and gamma rhythms, which in addition to bottom-up feature selection are particularly implicated in auditory perception, play an important role in the beat model, with gamma rhythms tracking beat prediction errors (Cadena-Valencia et al., 2018; Fujioka et al., 2009; Herff et al., 2020; Snyder & Large, 2005). Gamma may thus provide an internal "clock" to compare internal beats with external pulses (Bose et al., 2019).

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Developmental studies suggest that humans interpret rhythmic stimuli as social signals from an early age (Cirelli et al., 2018; Trainor & Cirelli, 2015). This bias may explain why beat perception and reward elicit positive social outcomes such as trust (Fiveash et al. 2023), supporting Savage et al.'s (2021) proposal that musical stimuli are linked with social prediction via the dopaminergic reward system. Musical rhythms are, then, social stimuli with uniquely repetitive and predictable temporal profiles, offering rich opportunities for minimizing social prediction error.[xiii] Susan's brain is suddenly finding prediction of her social surroundings easy and enjoyable.

However, humans can only perceive rhythms with periods of between around 0.2 to 2 seconds (Cannon & Patel, 2021; Kiebel et al., 2008). The motor system plays a central role in timing within this range, whereas longer-interval timing recruits working memory and conscious attention (Holm & Madison, 2013; Ivry & Spencer, 2004; Kotz et al., 2014; Lewis & Miall, 2003; Trost et al., 2017). Beats with periods longer than 2 seconds therefore tend to sound subjectively like disconnected events, requiring more top-down resources to process (Gilden & Mezaraups, 2022). Additionally, auditory processing affords greater temporal resolution than other sensory modalities (Burr et al., 2009; Comstock & Balasubramaniam, 2018; Gori et al., 2022). Beat perception thus imposes on Susan a particularly temporally fine-grained scale for social prediction, constraining her attention to narrow timing windows at the scale of the "subjective present" (Repp, 2005) (**Figure 2**).

Notably, beat perception easily triggers spontaneous overt actions, such as tapping one's foot absent-mindedly (Cannon & Patel, 2021; Grahn et al., 2012; Janata et al., 2012). This spontaneous entrainment results from the preparatory motor pulses that drive the brain's internal beat model; these seem not to specify particular effectors, instead capturing only the amodal rhythm (Cannon & Patel, 2021).[xiv] Thus, the urge to move in time could be equally expressed by nodding our head, drumming our fingers, or tapping our foot (cf. Evans-Pritchard, 1928).[xv] But in many contexts, we must suppress this urge, since synchronization can interfere with other tasks (Fiske, 1993; Wallot et al., 2016). For instance, if a danceable pop song comes on the radio while an important bakery customer is listing out an order, Susan ignores the beat and concentrates on the customer. She needs to access a longer-timeframe scale for processing and

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planning to navigate the interaction successfully. Attending the wedding reception after a long workweek thus offers an opportunity to relax this inhibition in a socially acceptable context.

3.1.2. Sensorimotor Synchronization

Once on the dance floor, sensorimotor synchronization (SMS) kicks in. Susan and the other guests disinhibit their covert rhythmic motor impulses to entrain their movements with the perceived beats while correcting timing errors to stay synced up (Repp, 2005; Repp & Su, 2013; Trost et al., 2017). In turn, SMS augments internal audiomotor responses to each pulse of the rhythm and so further reinforces beat perception, making the beat seem more stable and further diminishing granular prediction error (Cannon & Patel, 2021; Chemin et al., 2014; Koelsch et al. 2019; Manning & Schutz, 2013). Hearing or seeing other participants' synchronized actions enhances this reinforcement (Matthews et al., 2023). Group synchrony thus strengthens positive feedback between prediction, audiomotor connections, and reward (**Figure 2**).

This feedback is still further enhanced by" groove": the powerful, enjoyable urge to move in time to music that is moderately syncopated or unpredictable (Janata et al., 2012; Levitin et al., 2018; Matthews et al., 2023; Stupacher et al., 2022). Susan and the other dancers find such groovy tracks especially fun because, against the stable base rhythm, occasional surprises such as missed or offset beats generate particularly high-precision, information-rich prediction errors, which the brain eagerly exploits to improve its model of the beat and obtain reward (Kraus, 2020; Matthews et al., 2023). Hence, sensory sampling is enhanced (Hohwy, 2012). Moving in time also reinforces the internal beat model, allowing the dancers to override syncopated deviations from the rhythm. The drive to retain a useful beat model thus explains the particularly strong movement motive or "hop" that groovy music inspires (Koelsch et al., 2019; Matthews et al., 2023; Vuust et al., 2022). The dancers are using active inference to bring the perceived beat back in line with sensorimotor predictions.

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Figure 2

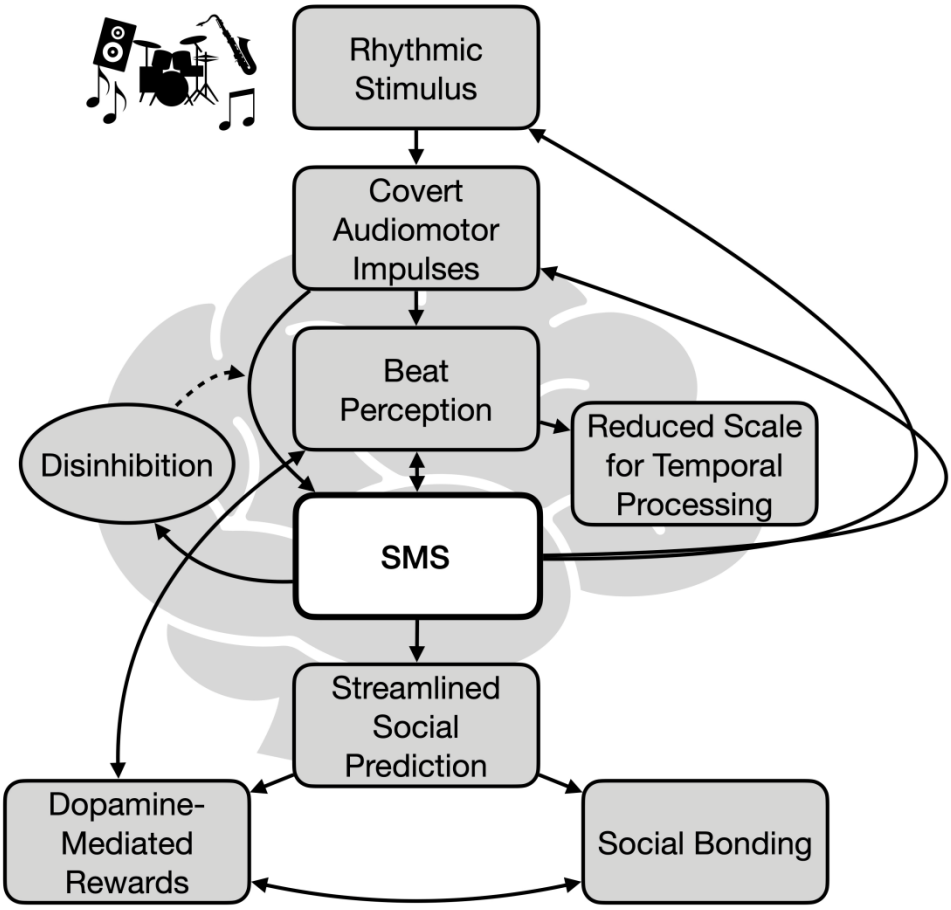


Figure 2 — Simplified causal model of feedback effects linking rhythmic auditory stimulus, beat perception and sensorimotor synchronization (SMS), and rewards and social bonding. Solid connections reflect direct causal influences. SMS reciprocally strengthens beat perception and contributes to the external rhythmic stimulus (e.g., the sound of clapping hands or stomping feet) in a reinforcing loop. Streamlined social prediction results in subjective rewards and interpersonal bonding. The dashed connection reflects a moderating effect: disinhibition is necessary to express covert beat impulses as overt motor synchrony. (Note that brain image is illustrative. No spatial correspondence is implied to particular networks for nodes in the model. Musical instrument symbols simply imply any rhythmic stimulus.)

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With its reliance on audiomotor processing of < 2-second temporal intervals, SMS has been described as "bottom-up entrainment" (Kobayashi et al., 2024, p. 23). This description is not strictly true, since the internal sensorimotor model in fact projects downward predictions to shape audio perception (Cheng et al., 2022). However, as I have been pointing out, the relevant predictive models are constrained to lower and intermediate levels of the processing hierarchy, where timescales are minute and abstraction is limited. We have entered low-construal territory. Again, prediction at this scale can scaffold simple but not complex joint action (Sacheli et al., 2022; Sebanz & Knoblich, 2009). Synchrony thus affords *dimension reduction* for social prediction, boiling it down to a series of temporal regularities at subsecond intervals. Bottom-up prediction error is salient and informative. Susan is able to intuitively predict with high accuracy when fellow dancers will move their bodies without calling to mind any high-construal information about who they are or what roles they play in daily life (**Figure 3**). Crucially, then, the internal model of the beat is not subject to the same accuracy-simplicity tradeoff that constrains high-level social priors (Section 2.2). It is both accurate at granular timescales and highly computationally efficient.[xvi]

3.1.3. Easier Synchrony Means More Rewards

Despite the universal appeal of synchrony, individual differences in timing ability, motor control, interpersonal attention, and related traits make some people better at staying entrained to the beat than others (Palmer et al., 2014). Difficulty maintaining synchrony with an unskilled partner triggers cascades of timing and social prediction errors that demand effortful self-correction, including shifting the timing of individual beats (phase correction) or calling up higher-level information to update the beat model (period correction) (Fairhurst et al., 2013; Harry et al., 2023; Praamstra et al., 2003; Repp & Su, 2013). That is, difficulty synchronizing awakens higher levels of the processing hierarchy, pushing participants back toward longer-timescale, more abstract and self-controlled modes of social prediction. It is thus associated with fewer rewards and less positive social outcomes (Cacioppo et al., 2014; Kokal et al., 2011).

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Figure 3

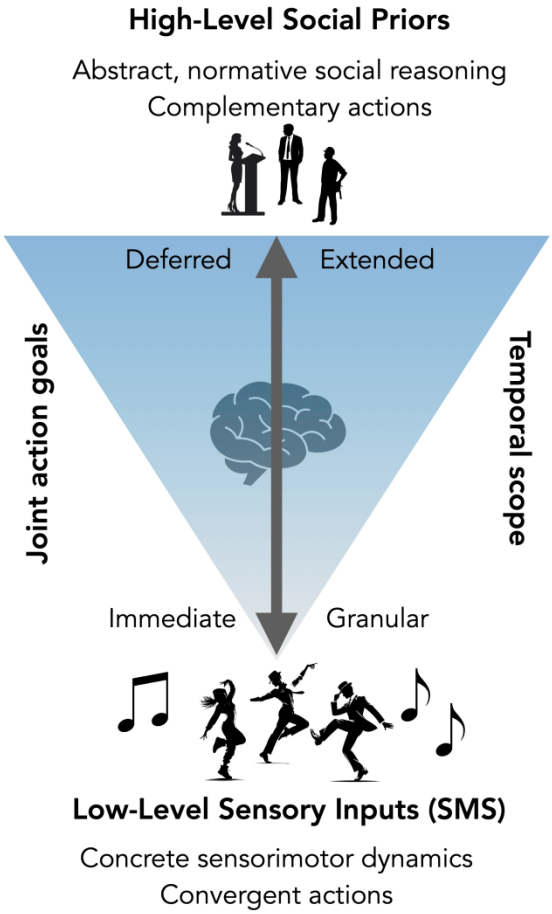


Figure 3 — The spectrum of goal scope and temporal processing scales in joint action. At the high end, top-down social reasoning is active; agents play normative, coarse-grained roles and often physically coordinate in complementary ways. High-level social priors are engaged and incentives are deferred, reflecting an extended scale for temporal processing and planning. At the lower end, bottom-up sensory (audiomotor) inputs predominate, and agents coordinate via convergent sensorimotor synchronization (SMS) to a mutual rhythm. The scope of temporal processing is granular and incentives are immediate.

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By contrast, easy entrainment powerfully activates subcortical reward centers, including the EOS and dopamine systems (Cohen et al., 2010; Kokal et al., 2011; Lang et al., 2017; Tarr et al., 2015). In the cortex, the ventral medial prefrontal cortex (vmPFC) is associated with rhythmic synchrony, social affiliation and closeness, and reward (Belfi, 2021; Bzdok, Langner, Schilbach, Engemann, et al., 2013; Cacioppo et al., 2014; Fairhurst et al., 2013; Haber & Knutson, 2009; Hiser & Koenigs, 2018; Savage et al., 2021; Yun et al., 2012). The vmPFC seems particularly recruited for processing bottom-up (granular and sensory-driven) social input (Bzdok, Langner, Schilbach, Engemann, et al., 2013). Interestingly, synchrony's benefits for trust seem to be mediated by the EOS (Lang et al., 2017), dovetailing with findings that endorphins produce feelings of social closeness and trust (Inagaki, 2018). The EOS partially overlaps with the dopamine system, which is also implicated in cooperative behavior and social reward learning (Mikus et al., 2023; Walsh et al., 2023). Thus, synchrony may activate the dopamine system for social prediction in a way that intrinsically elicits rewards via the EOS (Savage et al., 2021). Boosted dopamine signaling in turn shortens the perceived duration of time intervals (Holm & Madison, 2013; Ivry & Spencer, 2004). Stable or uninterrupted synchrony thus enhances the temporal granularity not only of objective processing windows but also of subjective experience, pushing the brain toward a more granular, low-level mode of social prediction with shortened time horizons while releasing rewards. Susan and the other dancers are literally living in the moment.

3.2. Self-Other Blurring

As Susan and the guests dance, they begin to feel a sense of subjective merging (**Feature 3**) (Biswas & Brass, 2024; Feng et al., 2020; Fujiwara et al., 2023; Koban et al., 2017; Wheatley et al., 2012). This merging can manifest as a sense of joint or extended agency, or the impression that one's agency is blurred with others' (Reddish et al., 2020). In hyperscanning studies, it corresponds to synchronized inter-brain activity, which may mediate synchrony's social benefits (Feng et al., 2020; although see Hu et al., 2017). Blurring likely results from a version of "enfacement," where simultaneous rhythmic stimulation to self and other causes confusion about body ownership because of temporal (not necessarily spatial) convergence between multisensory stimuli (Bauer, 2008; Botvinick & Cohen, 1998; Golaszewski et al., 2021; Hoehl et al, 2020;

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Mazzurega et al., 2011; Paladino et al., 2010). Synchrony extends this effect to encompass one's own motor behavior. The brain uses discrepancies between motor predictions and sensory feedback to make determinations about self-other boundaries (Brass et al., 2009; Cross et al., 2013; Kahl & Kopp, 2018). Action consequences that are simultaneous with our own movements lead to attenuation of the associated stimuli, a signal of self-agency (Hurley, 2008). What's more, near-simultaneity between one's own actions and external events causes intentional binding, in which subjects perceive the separate events as self-caused and even closer together in time than they actually are (Blakemore & Frith, 2003; Haggard et al., 2002; Hughes et al., 2013; Imaizumi & Tanno, 2019; Moore & Obhi, 2012). This effect explains the common illusion that we are controlling a metronome when in fact we are only synchronized with it (Solfo et al., 2019).

Many matches between input and sensory feedback over time strengthen intentional binding, particularly in the auditory channel (Ueda & Shimoga, 2023; Morita et al., 2012). Thus, if Susan moves her legs just as another dancer throws up an arm and a bass note booms from the speakers, she may sub-personally experience all these events as caused by herself, an effect that is compounded when repeated predictably (Hove, 2008; Hoehl et al., 2020). Cross et al. (2021) accordingly found that synchrony reduces self-other control, suggesting that motor representations of one's own and other's actions become mingled.[xvii] This realignment of self-other representations takes place at low and low-intermediate (sensory and sensorimotor) levels. Intermediate- and high-level prior beliefs that Susan and the other dancers are separate people with unique roles and personalities then acquire a low likelihood (the sensorium is not producing evidence that would be well explained by those beliefs) and so are relaxed, reducing total prediction error. The best predictive model becomes simplified, combined agency at low hierarchical levels (Heggli et al., 2021; Koban et al., 2019).

Neuroimaging evidence supports this interpretation. The temporoparietal junction (TPJ), an important cortical area for social cognition that also supports attention and sensorimotor integration, plays a central role in discriminating self from other (Brass et al., 2009; Duffy et al., 2019; Frith & Frith, 2006; Igelström & Graziano, 2017; Park et al., 2021; Schurz et al., 2017; Spengler et al., 2009). The TPJ contributes to the DMN (Lattanzio et al., 2021; Wang et al., 2020). In two studies (Cacioppo et al., 2014; Fairhurst et al., 2013), TPJ activity was reduced

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during synchrony with optimally synchronized VPs but enhanced when synchrony was difficult to sustain.[xviii] These findings reinforce the idea that, as synchrony becomes more unstable, participants must exert more cognitive control to update higher-level beat models and reorient attention using internal guidance. Bolstering this claim, alpha power in right parietal regions was enhanced in one study when duetting pianists were *not* synchronized while playing a familiar piece, suggesting a greater role for internal (top-down) processing when self and other are distinct (Novembre et al., 2016). By contrast, less prediction error during smooth synchrony means less need for tracking other independent agents. Harry et al. (2023) accordingly found that the TPJ was important for both phase and period correction during SMS. Synchrony may thus streamline social prediction not only by making audiomotor signals more stable (Section 3.1.2), but also by merging dynamic representations of self and other into a single, computationally tractable model requiring little top-down processing (Koban et al., 2019).[xix]

3.2.1. Blurring Scales Up

Interestingly, the TPJ and related areas also play key roles in processing high-construal ingroup-outgroup distinctions (Baumgartner et al., 2014). The TPJ is functionally connected for social cognition with another DMN node, the dorsomedial prefrontal cortex (dmPFC), which processes distant social others and outgroups and is important for high-construal reasoning more generally (Baetens et al., 2017; Mitchell et al. 2006; Mori & Haruno, 2022). The dmPFC also supports triadic social relations (Saxe, 2006) and appears to be recruited for ingroup bias (Gamond et al. 2017) and for processing counter-stereotypical social behavior (Pu et al. 2022). Sitting at or near the very top of the predictive cascade, the dmPFC thus seems to be activated by higher-level social prediction error relating to symbolic scripts, norms, and symsbols. And like the TPJ, the dmPFC is less activated when synchrony in dyads is stable and easy and more activated when it is unstable or difficult (Cacioppo et al., 2014; Fairhurst et al., 2013). This evidence suggests that blurring between group categories enjoys neurocognitive links with blurring between self and other (**Features 1** and **3**). In short, the local sensorium is failing to provide evidence for abstract social structure. As Susan and the other guests feel boundaries between individuals breaking down, priors that represent high-construal, conventional boundaries as the hidden causes of events lose likelihood and precision. Again, although other sensorimotor-based interactions can

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have self-other blurring effects (Apps et al., 2015; Maister et al., 2015; Mazzurega et al., 2011), only synchrony, with its audio dominance, easily scales up in this way to larger groups (Launay et al., 2016). Synchrony is thus capable of blurring self-other and intergroup boundaries in collectives of arbitrary size. Susan could come to feel more subjectively identified with a single member of the bride's family by playing a mirror game (Noy et al., 2015), but only synchrony lets her feel that her old family is unified with the whole (new) family at once.

3.3. From Exploit to Explore: The "Network Reset"

Overall, the regularity of the beat massively increases precision for low-level sensory prediction error across modalities (auditory, proprioceptive, vestibular, and visual) (Koelsch et al., 2019; Todd & Lee, 2015). As mentioned above, the high expected precision of the beat model lends salience to deviations, syncopations, or errors, capturing attention at low levels of the processing hierarchy and affording a particularly rewarding opportunity for granular model improvement (Koelsch et al., 2019). For instance, Quiroga-Martinez et al. (2019) found greater cortical mismatch negativity (MN) (a signal of sensory prediction error; Aaltonen et al., 2008) when subjects encountered oddball tones amidst otherwise highly predictable tone sequences than amidst entropic or noisy sequences. Because stable synchrony depends on low-entropy rhythms, audiomotor prediction errors necessarily enjoy high precision against the steady sensory background as Susan and the other guests dance. The dancers' attention is strongly bottom-up.

Accordingly, high-groove and syncopated music elicit pupil dilation, a sign of noradrenaline release (Bowling et al., 2019; Costa & Rudebeck, 2016). By shifting attention to incoming sensory evidence (particularly in the auditory channel; Bowling et al., 2019), noradrenaline facilitates prior updating and can enable a total "network reset" (Bouret & Sara, 2005; cf. Lawson et al., 2021; Yon, 2021). Noradrenaline is therefore released in response to unpredictable environments that call for heightened attention to bottom-up prediction error, the better to inform new and hopefully improved models; that is, it evokes neural plasticity (Jordan, 2024; Lawson et al., 2021; Marzo et al., 2009; Mather et al., 2016).

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Why would audiomotor rhythms and synchrony elicit noradrenaline release? Again, groovy music is intentionally rich in timing variations, which capture attention and ensure that the beat remains salient. That is, synchrony is highly predictable at the sensorimotor (interpersonal) level, but highly *informative* at the lowest sensory levels. Noradrenaline heightens focus on those levels. At the same time, the long-established statistical associations that facilitate everyday social prediction ("Susan is the boss, so we follow orders") are no longer evidenced in the sensorium. As we will see, this likely contributes to an entropic state at the highest levels of the hierarchy (Section 4). Noradrenaline thus indexes a "global model failure" (Jordan et al., 2024). Abandoning its usual strategy of exploiting habitual, top-down models and scripts, the brain shifts to an explore stance that gobbles up new bottom-up evidence, which is accumulated and processed (particularly in the vmPFC) to inform new, lower-error models in the lower hierarchy (Blanchard & Gershman, 2018; Graybiel, 2008).

3.3.1. Self-Regulation in a Bottom-up Mode

This transition has profound implications for self-regulation. Bottom-up attention implies a low construal level (Gilead et al., 2020). Low construal in turn is associated with relaxed self-control, since, as we have seen, goal-seeking requires extended time horizons and high construal of goals (Fujita et al., 2025). By contrast, immediate rewards increase approach behavior (Burghoorn et al., 2024) and decrease inhibition (O'Connor et al., 2021) (**Figure 4**). In light of the immediate rewards of audiomotor synchrony, then, *dancing or keeping rhythmic time is not "desire-independent*," but desire-congruent. Low-level processing focus during synchrony affords a temporary escape from top-down behavioral control as inhibitions are relaxed on prepotent impulses to move with the beat. Almost uniquely among types of joint action, then, synchrony combines precise, accurate social prediction with behavioral disinhibition resulting in pleasurable reward. Susan is having fun and blowing off steam even though she and the other dancers are more mutually predictable (at a granular temporal level) than they ever would be in daily life.

Crucially, the dancers' own disinhibited behavior itself offers further negative model evidence against high-level social priors, because these priors are normative: they demand active inference

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in service of jointly regulated goals (**Figure 4**). A disinhibited self is what they do *not* predict. Thus, during synchrony, active inference shifts from being concerned with performing mutually appropriate high-level roles to tracking (and reinforcing) a common sensorimotor beat with desire congruence. Pragmatically, this means that Susan and the other dancers do not care who plays what role during the workweek, since that knowledge is now useless for predicting what happens next on the dance floor for both self and other. Attention is instead captured at low levels of the processing hierarchy; intermediate-level priors are concerned solely with tracking and updating the local pattern of the beat; and high-level social priors remain relaxed.

Figure 4

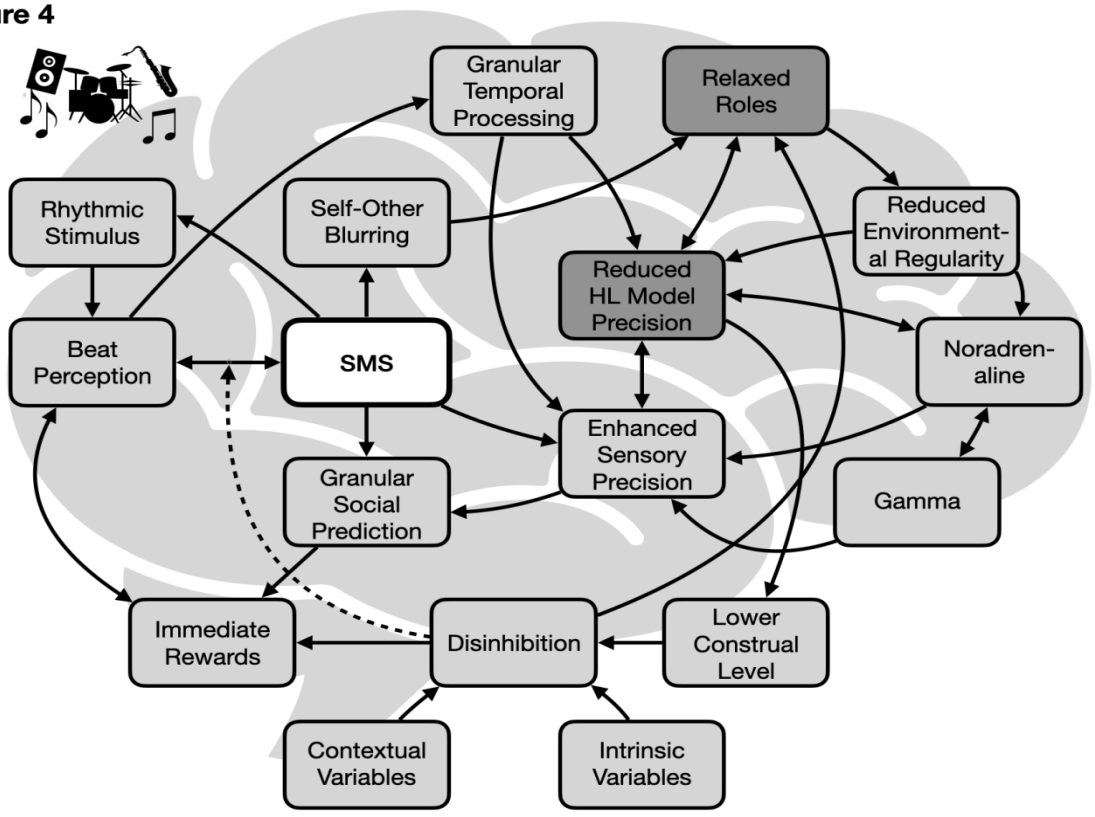


Figure 4 — Causal model of feedback effects linking audiomotor synchrony with relaxed top-heaviness for the social brain. Sensorimotor timing restrictions constrain temporal processing during beat perception and sensorimotor synchronization (SMS) to a local scale (< 2 s). The resulting bottom-up (sensory) precision triggers relaxation in precision for high-level (HL) social models and enhances granular predictability. Self-other blurring resulting from SMS contributes to a loss of salience for complementary HL roles, which in turn reinforces the decrease in HL model precision. Breakdown of HL roles also

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indicates a reduction in coarse-grained environmental regularity even as local sensorimotor prediction is streamlined, further weakening reliance on coarse-grained models and eliciting noradrenaline release. Noradrenaline and gamma partly mediate the connections between increased sensory precision, dampened environmental regularity, and weakened HL model precision, readying the brain to update HL models. Again, the dashed connection reflects a moderating effect: disinhibition facilitates the expression of the covert beat model as SMS. Disinhibition partly results from the lower construal level that flows from relaxed HL models, partly from contextual factors such as amount of groove in the rhythmic stimulus, and partly from intrinsic factors. Disinhibition in turn facilitates immediate rewards and strongly contributes to reduced salience for social roles that demand inhibitory planning and control. (Again, brain image is illustrative and does not imply spatial correspondence to particular networks for nodes in the model. Musical instrument symbols imply rhythmic stimulus.)

4. How to Change Your Priors With Synchrony

These relaxed priors can can now be revised. In general, when bottom-up data are low-noise, prediction error is salient and informative, making updates to priors more accurate (Hohwy, 2012; Quiroga-Martinez et al., 2019; Yon, 2021; Yon & Frith, 2021). At the same time, subjects are quicker to update priors in environments whose broad features are entropic (Behrens et al., 2007; Schmack et al., 2016). For instance, Fritsch et al. (2023) found that precise low-level prediction error in a stimulus led subjects to update priors more readily when *higher*-level environmental features (more coarse-grained statistical regularities) within the stimulus were noisy. Scaling up, synchrony may afford an analogous combination for social cognition. With normative roles and boundaries no longer evidenced, the coarse features of the social environment paradoxically become underdetermined. For example, Susan normally expects certain broad regularities in relations with her assistants (they obey her directions) and with cultural outgroups (they are distant and possibly untrustworthy). But as we have seen, amidst the dancing, these coarse regularities lose their coherence even as granular timing deviations become highly informative. Environmental predictability seems to weaken while sensory stability and bottom-up attention are boosted (**Figure 5A-B**).

Participants now encounter salient new social information they can use to update the temporarily relaxed global models. For instance, Susan's assistants usually expect her to avoid mirroring her

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subordinates at work (Liu et al., 2024; Tiedens & Fragale, 2003). They may anticipate feeling somewhat inhibited around her (Cho & Keltner, 2020), while Susan expects to affiliate more with ingroups than outgroups (Plötner et al., 2015). The sensorimotor experience of group dancing challenges each of these high-level priors, so the bakery assistants might form new posterior beliefs to the effect that Susan is not so socially distant after all, or that they need not always feel socially inhibited around her. All things being equal, then, the *flexibility of predictive models is enhanced by moving attention downward in the processing hierarchy*, particularly when perceived regularities at higher levels are unstable or uninformative.

Note that, far removed from the triadic and joint-intentional priors at the top of the hierarchy, the bottom-up evidence that propagates upward is in principle equally accessible to anyone with normal perceptual and sensorimotor systems, regardless of conventional or common knowledge. That is, Susan can dance just as well with foreign language–speakers as with English-speakers. By contrast, we have seen that the conceptual and normative contents of higher-level social priors are intrinsically restricted by group membership and status. Synchrony thus makes it easier to coordinate across group and individual lines than higher-level joint actions do (**Features 1-3**). The RePS model entails that relevant social priors thereby enjoy a window of plasticity in which to consolidate not only posteriors about group boundaries, but also about more articulated, explicit message contents, such as the wedding vows from the ceremony. Susan is prepped to form a variety of new posterior beliefs implied by the entire event: "my relative is married to this person"; "I am now related to this family."

4.1. Impressions Stick in the Plastic Brain

How stable are the new posteriors, though? Won't the brain just revert to its old beliefs after the dance tapers off? Undoubtedly, individual and contextual variables play a role here, but the neurobiological evidence strongly suggests that revisions to social priors will generally be consolidated after synchrony. Noradrenaline release and gamma oscillations both lead to synaptic plasticity and long-term potentiation (LTP), an important mechanism for Hebbian learning, in neurons in the hippocampus, thalamus, and cortex (Griffiths & Jensen 2023; Neves et al. 2018; Nguyen & Gelinas 2018; Tully et al. 2007), including deep-layer cortical cells (Xing

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et al., 2017). Gamma oscillations synchronize presynaptic neuron spikes, boosting signals into postsynaptic neurons and eliciting spike timing–dependent plasticity, and so encourage associative binding between different sensory stimuli to encode memories (Griffiths & Jensen, 2023). By increasing stimulus-driven excitability in these regions, noradrenaline enhances working and long-term memory and recall (Bacon et al., 2020; Carr et al., 2007; Sampaio et al., 2020). Dopamine also plays a critical role in inducing synaptic plasticity and encoding of long-term memories (Diederen & Fletcher, 2020; Speranza et al., 2021). Accordingly, dopamine production from musical rhythm helps enhance memory formation (Fiveash et al., 2023), and musical reward facilitates episodic memory storage and recall for associations external to the music itself (Cardona et al. 2020). Synchrony also boosts recall for incidental memories formed during brief interactions (Macrae et al., 2008), particularly when entrainment is intentional (Cross et al., 2021).

Importantly, LTP elicited by noradrenaline and gamma oscillations can endure for weeks, about the amount of time needed to shift a new memory from short-term storage in the hippocampus to long-term encoding in the cortex (Escobar & Derrick, 2007). Hence, the period of plasticity for social beliefs likely endures for some time *after* the dance is over. If Susan runs into one of her new in-laws tomorrow, she will likely remain receptive to new information about them (Section 6.1.2). Neurohormonal modulation of attention during synchrony therefore plays a crucial role in plasticity, prepping the brain to encode new memories that anchor updated beliefs (cf. Dahl et al. 2022; Nyhus & Curran 2010) (**Figure 5C**).

4.2. Leveraging the Entropic Brain

This plasticity can be described in terms of entropy (cf. Carhart-Harris & Friston, 2019). Recall that top-down predictions represent the content of priors, whereas the variance (spread in probable outcomes) represents prior precision (Frith & Yon, 2021). An energy landscape pocked with deep, narrow "prior basins" is stable and highly canalized, with high-precision priors tightly constraining attention and cognition and filtering out most sensory evidence. A ball that drops into a deep basin in this landscape tends to stay there; the brain does not easily move between predictive states (**Figure 5A,C**). By contrast, a flat landscape with shallower basins is less stable,

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equating to more noisiness or entropy and smoother transitions between states as the ball easily rolls across divots (Beneš et al., 2025; Carhart-Harris et al., 2014; Singleton et al., 2022) (**Figure 5B**).

The entropic brain hypothesis (Carhart-Harris et al., 2014) proposes that the "richness" of conscious experience under the influence of psychedelic drugs indexes this entropy in brain activity, in contrast with greater orderedness (top-down canalization) during everyday cognition. Carhart-Harris and Friston (2019)'s model of "relaxed beliefs under psychedelics" (REBUS) analogizes the resulting brain plasticity to annealing, in which materials are heated to homogenize microstructure and relieve internal stresses, allowing recrystallization in a new state. Repurposing this analogy, we might say that as Susan loses herself in the dance, her sensory background becomes more ordered and informative, yet the highest levels of her brain's processing hierarchy become annealed and unstructured. Paradoxically, an especially ordered sensorium is the distal cause of cognitive entropy. This flat topography makes it easier to shift to new beliefs about whether the bride's family are ingroup or outgroup, relatives or strangers. This occurs rapidly, without requiring many separate encounters to slowly wear away prejudices (**Feature 2**). In the days afterward, the LTP elicited by synchrony gradually wears down as relevant new memories are re-encoded from the hippocampus to the cortex. Her brain's energy landscape slowly returns to a top-heavy state, but with reconfigured basins to accommodate new priors (**Figure 5C**).

This analogy helps explain the subjective richness or intensity of dance or synchrony (e.g, McNeill, 1995). Of course, psychedelics and synchrony use different mechanistic pathways to achieve their entropic effects. Psychedelics such as psilocybin are agonists for 5-HT2A serotonin receptors, which are densest in deep-layer pyramidal neurons in high-level cortical association areas such as the dmPFC (Carhart-Harris et al., 2019; Singleton et al., 2022). By increasing the excitability of 5-HT2A receptors, psychedelics are thought to boost variability in neuronal spike patterns in these regions and so reduce the precision of high-level priors, weakening top-down control over perception.[xx] Accordingly, psychedelic trips typically suppress cortical alpha wave power (Alamia et al., 2020; Herzog et al., 2023). Alpha increases redundancy of neuron spike patterns and thus gates the amount of information propagated through the brain, reflecting the

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information-compression function of coarse-grained priors (Dahl et al., 2022). In this way, psychedelics appear to directly relax priors at high levels of the hierarchy, leading to potentially long-term changes in self-relevant beliefs (Zeifman et al., 2025).

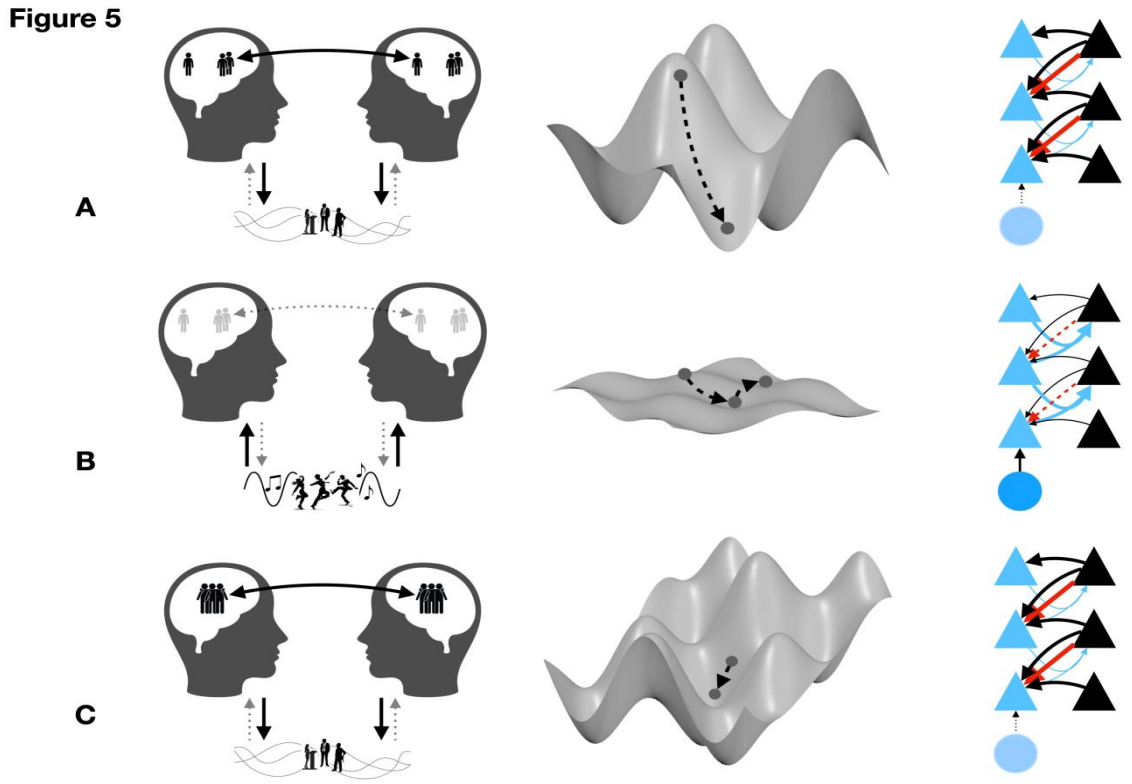


Figure 5 — Relaxation of cognitive top-heaviness and revision of rigid social priors stimulated by rhythmic synchrony. In **5A**, triadic (joint attentional) relations between agents and the environment reinforce top-down belief in distance between social groups. Solid bidirectional arrows between agents' minds represent robust, mutually sustained high-level social priors, and solid top-down arrows from agents to sensory context represent strong constraints (high precision) of models over bottom-up signal. Defined roles are salient and granular sensory signal is irregular and noisy. Correspondingly, the brain's energy landscape is characterized by deep basins and high peaks, making transitions between attractor states difficult. In **5B**, rhythmic synchrony renders sensory signal more regular and high precision, allowing for stronger bottom-up attention and the relaxation of triadic assumptions about intergroup boundaries, as behavior determined by role templates gives way to relatively disinhibited entrainment to the beat. Agents

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enter a high-entropy cognitive state in which the brain's energy landscape flattens out, allowing for easier transition between states. After synchrony, top-heaviness reasserts itself, but with new triadic beliefs installed in which previous group boundaries are overcome and previously distant participants are understood as shared group members; the energy landscape is once more pocked with deep basins but in new configurations (**5C**).

The schematics on the right of each figure **5A-C** represent predictive processes in the brain at each stage of progress from top-down to bottom-up social coordination and back again. Black triangles are hierarchically organized prediction units, and black arrows represent inhibitory top-down models; blue triangles are error units, and blue arrows represent excitatory (upward) prediction error signals. Red arrows represent precision weighting for predictive models, which moderate between-level top-down connections. When sensory evidence is imprecise (blurry input in **5A,C**), precision weighting for predictions is strong (thick red arrows) and sensory evidence is robustly constrained by model predictions (thick black arrows) as it passes up the hierarchy, leading to relatively weak belief updating. When sensory evidence is high precision (clear input in **5B**), top-down precision is relaxed (thin dashed red arrows), allowing bottom-up evidence to propagate more robustly up the hierarchy and inform belief updating (thick blue arrows).

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By contrast, synchrony is not known to directly upregulate 5-HT2A receptors (Waters, 2021).[xxi] Further, in one important study, exposure to rhythmic drumming elicited no decrease in alpha but rather an increase in gamma power among shamanic practitioners (Huels et al., 2021), comporting with the role of gamma in beat perception (Bose et al., 2019). When considered in light of noradrenergic response to groovy beats (Bowling et al., 2019), synchrony seems instead to drive high-level entropy from a bottom-up direction by boosting the gain on upward flow of sensory prediction error, as I have argued. The RePS model nevertheless implies that many high-level effects of synchrony and psychedelics will converge. This expectation is, in turn, supported by the culturally widespread role of rhythmic music and dance in catalyzing **Feature 4**: trance.

4.3. Going Deeper: Trance Is the Dramatic Relaxation of Priors

Imagine that the wedding celebration continues late into the night. Eventually the music transitions from well-known pop hits to electronic tracks with repetitive, driving beats mixed in a continuous stream. At some point, Susan might start to feel her conscious experience shifting. The background and other dancers fade from her direct awareness as, absorbed in the musical rhythm, she hones in on interoceptive and proprioceptive sensations. The RePS model implies a mechanistic basis for the trance Susan is entering (**Feature 4**) (Bourguignon, 1976; Campbell, 2023; Dunbar, 2020; Singh, 2018; Winkelman, 2015).[xxii] Like psychedelics, rhythmic trance has been shown to induce neural signals of criticality or entropy (Huels et al., 2021). This release of top-down inhibitions may allow the liberation of internal cognitive content that is normally gated or filtered out by strong priors (cf. Carhart-Harris & Friston, 2019). In other words, heightened entropy at the top of the processing hierarchy may cash out in less canalized, more spontaneous and intense subjective experience, including heightened salience not just for sensory prediction error, but also for internal bottom-up data such as emotions, interoceptive perceptions, and impulses.

Reports that gamma power is enhanced in shamanic practitioners during trance drumming (Flor-Henry et al., 2017; Huels et al., 2021) support this prediction and dovetail with Cho et al. (2018), who reported that perceptions of efficacy for a spirit medium ritual were associated with decreased alpha and beta power, suggesting a role for relaxed top-down predictive inhibition.

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Accordingly, in Maurer et al. (1997), subjective trance levels in participants were enhanced when 15 minutes of performing (not merely listening to) repetitive drumming preceded hypnosis, while another study found that listening to repetitive drumming led to more dreamlike experiences in conditions with shamanic instructions (Gingras et al., 2014).

4.3.1. Trance Frees the Top of the Hierarchy

However, Balinese spirit trance was associated with increased alpha power in Kawai et al. (2017). This discrepancy may reflect that the rhythmic stimulus in this study was slower tempo than Huels et al. (2021; cf. Harner, 1997). Slow musical tempo has been found to induce alpha, whereas faster tempo induces gamma and increases positive emotional valence (Yang et al., 2025). Forms of trance stimulated by slower-tempo rhythms, such as in Kawai et al. (2017), may decouple the agent from surroundings by providing a highly predictable, low-arousal stimulus that causes sensory cancellation. Supporting this proposal, Lanzilotti et al. (2019) found that event-related spikes in brain activity for each beat weakened when subjects listened to rhythmic music over time, reflecting the brain's suppression of overdetermined stimuli. Nevertheless, the same, slow-tempo Balinese trance dance was found in an earlier study to correlate with noradrenaline release, suggested unstable priors (Kawai et al., 2001).

Different types of rhythm-driven trance therefore seem to align in changing the balance between top-down and bottom-up processing in ways that boost gain on low-level feedforward signals. The trance Susan enters on the dance floor is driven by fast-tempo rhythm and is positively valenced, with enhanced gamma and noradrenaline release. Although she may be strongly engaged by microtiming variations and so less decoupled from sensory signals than a slow-moving Balinese trancer, neither are using everyday high-level priors to navigate their social surroundings. The brain may thus become absorbed in lower-level sensory signals or call up imagery and associations unconstrained by either immediate sense data or top-down predictions (cf. Smallwood et al., 2012). This decoupling of the "top" of the hierarchy from the environment would potentially reconcile RePS with findings that rhythm-induced trance boosts activity in nodes of the DMN such as the posterior cingulate cortex (Hove et al., 2016). Rather than indicating increased top-down control, Hove et al.'s results might indicate that high-level

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networks are exploring novel regions of conceptual state space, generating hallucinations and unexpected associations in an altered state of consciousness. Accordingly, rhythmic music and dance have been found to be more effective at inducing trance states than psychoactive drugs (Schäfer & Kreuzburg, 2023).

In light of the mechanistic story I have been telling, then, synchrony-induced trance states represent an even more dramatic flattening of the brain's self-organizing landscape than typical synchrony, allowing for more novel associations and deeper revision of high-level generative models. These dissociative trance states can in turn be culturally deployed in different ways (Seligman & Kirmayer, 2008). Ritualized spirit possession, for instance, involves temporary, often pronounced changes in behavior and personality interpreted as channeling spirits or ancestors, nearly always in the context of rhythmic music and dancing (Bourguignon, 1976; Seligman & Kirmayer, 2016). These possession events seem to imply dramatic relaxation of social and self-related priors.[xxiii] Supporting this proposal, Felmingham et al. (2008) found that dissociative responses were characterized by reduced activation in the dmPFC, suggesting attenuated processing of high-construal social beliefs. Similarly, in Rogerson et al. (2021), shamanic drumming reduced activity in a related DMN area, the orbitofrontal cortex.

Trance thus appears to occupy the far end of a continuum, with one pole representing stable social priors and top-heavy canalization of everyday life. Moving away from that pole, mildly relaxed top-heaviness and cognitive entropy during synchrony gently induce plasticity, preparing the social brain for workaday transformations in group categories, status roles, or other high-construal representations without necessarily triggering trance (**Features 1-3**). These mildly entropic effects would explain how, in contexts such as weddings or community rituals, "music can function in the restructuring of social relations" Cross (2001, p. 32). **Feature 4** and phenomena such as ritualized spirit possession are what we find if we continue down the continuum toward the far pole. Rhythm-induced trance is the extreme case of the relaxed top-heaviness resulting from synchrony.

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4.3. Out with the Old, In with the New: Implications for Mental Health

As such, we might expect synchrony to have REBUS-like effects in domains beyond trance and altered states of consciousness. One such shared effect is self-other processing, which is disrupted by both psychedelics and synchrony (Cross et al., 2021; Smigielski et al., 2020). More provocatively, Carhart-Harris and Friston (2019) suggest that cognitive annealing explains the putative therapeutic benefits of psychedelic drugs for disorders such as depression, which can implicate maladaptive but rigid higher-order beliefs about the self. In this telling, relaxation of top-heavy brain function by psychedelics allows for the breaking down and adaptive revision of unhelpful beliefs.[xxiv] Other approaches have similarly argued that relaxed beliefs and increased sensory precision may benefit mental health, as in meditation (Manjaly & Iglesias, 2020), and "pivotal mental states" triggered by stress-induced serotonin flooding (Brouwer & Carhart-Harris, 2021). Along these same lines, eye movement desensitization and reprocessing psychotherapy may help patients challenge maladaptive priors formed during traumatic experience by increasing sensory sampling from the bottom up (Chamberlin, 2019). In light of these arguments, it is intriguing that a recent meta-analysis (Noetel et al., 2024) found that dance was the single most effective therapy for depression among an extensive list of treatments, including SSRI medications, weight training, and cognitive-behavioral therapy. By drawing attention to regular, rhythmic events at small timescales and inducing high-level cognitive entropy, synchrony may offer potential for breaking out of maladaptive mental loops.

5. Not Everyone Wants Change (Or, Why Authorities Hate Your Party Music)

To summarize thus far, the mechanisms and effects of synchrony point to functions that go far beyond social cohesion, although bonding is one important outcome. Indeed, Susan feels newly close to her in-laws and assistants after the reception dance. Yet instead of shoring up "groupish" values, synchrony also crosses group boundaries, rapidly bonds strangers, and blurs or flattens authority relations (**Features 1-3**), and at its extremes induces trance (**Feature 4**). In reducing the complex task of social prediction to a low-dimensional problem of temporally fine-grained beat perception and entrainment, synchrony induces entropic plasticity at higher levels, circumventing the abstract categories that typically ground participant status, group identity, and

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even self-models. This amounts to an ability not only to quickly bond participants, but, at a psychological level, to temporarily "switch off" high-construal boundaries of status, ingroup, and role. Transcending group boundaries, rhythmic music in this sense indeed offers a "universal language" (Longfellow, 1848, p. 202).[xxv]

Perhaps paradoxically, these entropic effects and universality in turn explain why cultural authorities sometimes mistrust and even forcefully sanction heavily rhythmic music and dance (**Feature 5**). This propensity is found across cultures and historical eras. Puritans famously rejected dance (Wagner, 1997). In Confucian philosophy, Xunzi warned that loud or energetic music was morally corrupting (Kim, 2023), while the Florentine Savonarola burned musical instruments in his 1497 bonfire of the vanities. Phillip II of Spain banned all church music other than Gregorian chant, which is incompatible with synchronized movement (Barzun, 2000; Mosebach, 2002), and the twentieth century saw fierce debates surrounding rock n 'roll and other musical genres that emphasize heavy beats (Deflem, 2020; Gioia, 2019). It seems unlikely that so many disparate authorities would have reservations about rhythmic music if synchrony simply helps people get along. Conceiving of synchrony as a means for relaxing cognitive top-heaviness speaks compellingly to this quandary. Typically, leaders aim to compete against other groups and command resources and so have vested interest in successful joint and collective action (Handley & Matthew, 2020). The conditions for this include stable roles, statuses, and hierarchies that facilitate division of labor and mutual long-term predictability. It is unsurprising that those most invested in collective competition (and their rank within the hierarchy) might look askance on music that relaxes the high-level priors that sustain such conditions.[xxvi]

It follows that, what while some expressions of mistrust toward rhythmic dancing could reflect a fear of subordinates bonding together to constitute a new coalition-level threat (cf. Mehr et al., 2021), the more common anxiety seems to be simply that relaxed inhibitions and self-control will break down the structures on which authorities depend. In other words, RePS entails that authorities are not mainly afraid that expressive synchrony will conjure up organized cells of resistance (an implication of cohesion-based theories of synchrony), but that disorganization and weakening of boundaries will undermine social self-regulation, leadership, and coordination. For example, it has been suggested that the advent of punk rock, driven by heavy, energetic drum

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rhythms, played a role in the breakdown of East Germany by expressing widespread dissatisfaction with communist norms (Gioia, 2019). But punk rockers do not typically make outstandingly cohesive units. If punk rock did indeed contribute to the regime's collapse,[xxvii] social bonding and coalition signaling were not the means. Instead, it amounted to a chaotic challenge to top-down joint regulation *per se*.

5.1. Synchrony Unites, Ritual Divides

This insight can also be applied to rituals in general, a domain where music and synchrony often feature prominently. Cultural rituals feature frequently serve to assign or reinforce statuses (Rappaport, 1999; Smith, 1992). Hobson et al. (2018) associate the physical features of ritual with bottom-up, input-driven processing and its representational features with top-down and deontic processing. In this schema, synchrony and dance seem particularly heavily weighted toward the physical, bottom-up end of the scale (Wood, 2021). By contrast, a ritual act that creates a new status, such as the exchange of wedding vows, emphasizes top-down input. It is noteworthy that, in Western weddings, the exchange of vows is characterized by solemnity and turn-taking for participants. That is, at precisely the moment when the new status is decisively conferred, the new couple, officiant, and guests are *not* rhythmically unified. It is only afterward, at the reception, that rhythmic music and dancing make their entry, allowing the newly joined families to encounter sensorimotor evidence of literal social union and to consolidate posteriors about the new status.

In this way, RePS accounts for the observation that music unites, but language and ritual divide (Seligman et al., 2008; Yutang, 1942). It sheds explanatory light as well on the common intuition that music is "natural" as against the artificiality of conventions or culture (Cross 2009). Namely, rhythm and synchrony relativize the subjunctive, joint-intentional boundaries that compose social structures. Anti-structure "feels" natural because it is *not* socially constructed. Ceremonies that emphasize expressive synchronous rhythm, such as Pentecostal worship services, are accordingly often associated with homogenization or blurring of roles, flattened hierarchies, and spontaneous behavior rather than differentiation, inhibition, and hierarchy (e.g., Alexander, 1989). As Douglas (1970/1996) argued, conflicts within religious communities about whether or

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not to use rhythmic music in ritual thus often reflect deep tensions between egalitarian, anti-structural values (pro–rhythmic music) and collectivistic, structural ones (anti–rhythmic music). At the same time, different stages in a single ritual may emphasize top-down status changes (the exchange of vows) and the relaxation of priors to enable those changes to "take" or consolidate (the reception), as in a processual view of ritual (Turner, 1969).

6. Predictions

6.1. Neurobiological

The RePS model suggests avenues for empirical testing at several levels. At the neurobiological level, it predicts changes to brain activity associated with error monitoring. Error-related negativity (ERN), a component of event-related brain potential, responds to even unconscious performance errors (Nieuwenhuis et al., 2001). If RePS carves reality at its joints, ERN in response to perceived role-incongruent or counter-normative behavior should be attenuated during or immediately after synchrony. That is, if synchrony relaxes precision for high-level social priors, evidence that one's own behavior contradicts those priors should be less salient and arouse weaker ERN after synchrony than before. This prediction receives tangential conceptual support from previous research showing that repeated performance of a novel ritual over the course of a week reduced ERN in participants (Hobson et al., 2017). However, in the case of synchrony, ERN reductions should result from a single performance. Susan might therefore not experience flashes of self-critique when behaving excessively familiarly with relative strangers after dancing at the wedding. Relatedly, MN should also be decreased. This effect might be particularly strong for social auditory input such as speech. MN might be hence be weaker in response to foreign accents after synchrony than before (note the implied weakening of cultural boundaries.)

Relatedly, there should be heightened signals of LTP in the hippocampus, thalamus, and cortex in the hours and days after synchrony. However, if the plasticity effects of synchrony are strongly mediated by noradrenergic activity, antagonism or interruption of noradrenaline pathways should attenuate or eliminate LTP and other plasticity mechanisms (cf. Lawson et al,

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2021). Administration of propanolol, a noradrenaline antagonist, should therefore reduce the strength of **Features 1-4** by artificially suppressing bottom-information flow for model updating (cf. Yon, 2021). Finally, the brain should exhibit signatures of heightened entropy in spontaneous activity overall during and immediately after synchrony, particularly in deep cortical layers, perhaps increasing with greater duration of participation. These signatures may include heightened criticality and scale-free organization in neural activity (Muthukumaraswamy & Liley, 2018).

6.2. Psychological

At the psychological level, all things being equal, synchrony should elicit low-construal processing. This could be indexed by reduced psychological distance along temporal, spatial, social, and hypothetical dimensions (Trope & Liberman, 2010). For instance, while positive social affect might increase after synchrony, we could hypothesize a drop-off in politeness, which tracks social distance and recruits inhibitory self-control (Stephan et al., 2010). Susan's assistants might thus deploy less grammatical formality in speaking with her during or immediately after the dance, perhaps dropping the subjunctive modal verbs and mitigators they typically use at the bakery. Synchrony should also elicit greater delay discounting and other signs of relaxed self-regulation indicative of low construal (Fujita et al., 2025). Additionally, dovetailing with the entropic brain hypothesis, synchrony might elicit comparatively greater levels of "richness" in conscious experience than non-synchrony conditions. These could include more intense subjective experience of sense perceptions extrinsic to the auditory pulse (for example, colors or ambient temperature) as constraints on bottom-up signaling are relaxed.

At the social-psychological level, transitions in social structure or roles should achieve greater consolidation and stability when followed or accompanied by synchrony than otherwise. For instance, participants might show greater processing fluency when pairing individuals with new roles if the role transition was punctuated by synchrony. This effect is expected because, from the perspective of the top of the hierarchy, the role transition is the best explanation for the sensorimotor fluency and social unity experienced with the group during the celebratory dance. (Note that social-cohesion explanations of synchrony make no equivalent prediction.) Similarly,

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new members of an ingroup should be less fluently paired with outgroup associations or negative prejudices if their integration into the group was marked by synchrony.

A third psychological prediction is that, under controlled conditions, synchrony might alleviate mental health symptoms stemming from overly rigid social or self-models. This prediction is supported by Noetel et al.'s (2024) finding that dance is superior to other forms of exercise for treating major depression. Despite resulting from different mechanisms than psychedelic trance, global annealing of high-level priors during synchrony could thus provide similar opportunities for challenging maladaptive cognitive patterns or rumination.

6.2.1. Negative Psychological Effects

However, just as excessive psychedelic use can be harmful (Bremler et al., 2023), we might predict that especially strong or long-lasting states of post-synchrony plasticity could entail psychological risks. For instance, behavioral "addiction," associated with escapism and psychiatric disorders, affects a small minority of dancers (Maraz et al., 2015).[xxviii] Risk factors such as escapist motivations, adverse life events, and unstable or dangerous contexts could thus interact to induce maladaptive reliance on synchrony for psychological coping. Notably, psychedelic abuse increases anxiety, reflecting a weakened capacity to successfully explain away sense data (Bremler et al., 2023; Harris et al., 2023). While synchrony boosts the predictability of low-level sensory input in the short term, chronically overweighted bottom-up signaling from synchrony overexposure could thus induce anxiety-like symptoms as coarse-grained, stabilizing regularities disappear from one's social models. Such symptoms might include increased self-consciousness and excessively low-level focus during motor tasks (Harris et al., 2023).

Paradoxically, social cognition in particular could be impaired. The symptom profile would possibly resemble autism spectrum disorder (ASD), which is associated with poor social cognition (Hou et al., 2023; Moran et al., 2011; Schuwerk & Sodian, 2023) and impaired triadic reasoning and joint attention (Baron-Cohen, 1987; Frith et al., 2003; Westby, 2022; Williams et al., 2018). Notably, ASD is increasingly thought to result from chronically boosted gain on bottom-up sensory signals (Andersen, 2022; Cui et al., 2025). Children and adolescents with

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ASD accordingly exhibit weakened ERN and MN (Larson et al., 2011; Lassen et al., 2022) and enhanced somatic self-consciousness (Lavenne-Collot et al., 2023). Synchrony overexposure or behavioral addiction could elicit similar symptoms if gain on bottom-up sensory input is chronically enhanced.[xxix]

These predictions may seem counterintuitive, given that synchrony and dance typically benefit mental health (Aalbers et al., 2017; Ho et al., 2011; Noetel et al., 2024; Reagon et al., 2016) and psychosocial functioning among subjects with ASD (Applewhite et al., 2022; Dvir et al., 2025). However, synchrony's effects on anxiety and stress are moderated by sex, personality, and other factors (Papasteri et al., 2020). Future research could identify whether specific traits or contextual factors put certain categories of synchrony participants at risk of behavioral dependence and heightened anxiety. Relatedly, while some research has argued that synchrony improves perspective-taking and other mentalizing skills (Baimel et al., 2015; Wheatley et al., 2012), more recent findings suggest that, although synchrony indeed enhances subjects 'self-reported drive to engage in social cognition, it does not actually improve performance (Baimel et al., 2018; Basile et al., 2022). For instance, Wan et al. (2022) showed that asynchronous and anti-phase musical coordination improved children's perspective-taking, but synchronous coordination did not. These findings are interpretable in light of the role of self-other control in general social reasoning (Sowden & Shah, 2014). The relationship between synchrony and social functioning is thus complex; interpersonal entrainment and aligned attention in synchrony may not always benefit social cognition straightforwardly, and maladaptive reliance on synchrony offers fertile avenues for inquiry.

Importantly, the counterintuitiveness of these predictions makes them particularly helpful for differentiating the RePS model from closely related alternatives, such as the music and social bonding hypothesis (Savage et al., 2021). Under the view that synchrony primarily serves group cohesion, any psychological "dark side" of synchrony is limited to heightened groupishness and conformity, such as unquestioning obedience to authority, inhibited creativity, and the risk of outgroup exclusion (Gelfand et al., 2020; Kempf, Benedek, et al., 2024; Wiltermuth, 2012). Indeed, Savage et al. (2021) explicitly connect social bonding in (particularly rhythmic) music to out-group exclusion and parochial altruism. Conceptually supporting these associations,

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Galbusera et al. (2019) reported that synchrony hampers emotional self-regulation because of excessive coupling between participants. By contrast, RePS implies that many negative consequences of synchrony result from the breakdown of higher-order social priors and boundaries, along with associated top-down regulation.

6.3. Cross-Cultural

At the cross-cultural level, another crucial prediction is therefore that synchrony should not necessarily be linked with cultural "tightness" or conservatism (contrast Gelfand et al., 2020; Haidt et al., 2008). Indeed, it might even encourage cultural fluidity and antiauthoritarianism (Douglas, 1970/1996). Rave culture, for instance, centers on rhythmic dance and tends to be strongly egalitarian and antiauthoritarian (Winkelman, 2015). This prediction receives tangential support from cross-cultural research showing that highly arousing, "imagistic" ritual forms (often dance-centered) are disproportionately found in small-scale, more egalitarian societies, while more restrained rituals cluster in larger, more hierarchical societies (Whitehouse, 2021). To the extent that synchrony, particularly expressive versions, contributes to ritual arousal and opposes top-down restraint, we might expect that the prevalence of ecstatic synchrony may follow a similar cross-cultural pattern (cf. Savage et al., 2021).

However, a more detailed look at the data hints at a more complex pattern. Alcorta and Sosis (2020) found that the distribution of costly male cohort initiation rites across societies follows a U-shaped curve: rare in hunter-gatherer cultures, common in mid-complexity societies, and rare again in highly complex societies. These results likely reflect strong cultural selection pressure for in-group cohesion and solidarity at the *middle* range of social complexity, where land tenure and descent groups (i.e., collectivistic institutions) pervasively organize society. By contrast, mobile hunter-gatherer bands feature flexible, fission-fusion structure with opportunistic collaboration across wide networks (Bird et al., 2019). Similarly, modern industrial societies reward opportunistic social and economic strategies for wide-scale anonymous cooperation, which would be threatened by strongly bonded clans or subgroups (Henrich, 2020). Tightly fused male cohorts produced by costly initiation rites are therefore poorly suited to both foraging and modern industrial niches. If synchrony is a mechanism for cohesion, bonding, and

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conformity, we might therefore expect a similar U-shaped curve: lots of synchrony in middle-complexity farming societies that demand strong solidarity and bonded clans, but less in the individualistic contexts of foraging or industrialized societies. By contrast, if synchrony induces flexibility, we should expect precisely the opposite U-curve: high emphasis on synchrony in foraging societies; more sanctioning against synchrony in middle-complexity, "traditional" societies; and weakened restrictions on rhythmic group synchrony in complex modern societies. The latter prediction gains circumstantial support from the increased prevalence of 20th-century musical styles that support group dance in large but otherwise unorganized crowds (Gioia, 2019).[xxx] Notably, both U-curve predictions run counter to Savage et al. (2021), who predict a strict linear decrease in "participatory music" (paradigmatically, rhythmic dancing) as societal complexity increases.

A final cross-cultural prediction stems from comparative biomusicology. Namely, the so-called "shibboleth" function of music, by which cultural ingroups reject outsiders with unfamiliar musical styles (Savage et al., 2021), should be more strongly associated with melodic and tonal features of music than with rhythmic features. Rhythmic features that facilitate synchrony, by contrast, should *ceteris paribus* invite comparative openness to members of dissimilar backgrounds. Other empirical avenues for testing cultural predictions flowing from RePS may be identified as researchers derive inferences from the model.

7. Discussion and Conclusion

7.1. Evolutionary Implications

A rich and growing literature explores the evolutionary and phylogenetic origins of synchrony (Cannon & Patel, 2021; Fitch, 2015; Merchant et al., 2018; Patel, 2021; Patel & Iversen, 2014; Ravignani et al., 2016; Wilson & Cook, 2016). A comprehensive evolutionary analysis of synchrony is beyond our scope, but I wish to briefly outline some evolutionary implications of the RePS model. This discussion grounds itself on the fact that human SMS abilities are uniquely well developed. While individuals from species such as parrots and sea lions can flexibly entrain to musical rhythms (Cook et al., 2013; Jao Keehn et al., 2019; Schachner et al., 2009), these

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abilities are comparatively rare and apparently not species-typical. Beat synchronization is less flexible in these animals, with reduced range for error correction and duration of entrainment compared (Wilson & Cook, 2016). SMS abilities are even more constrained among chimpanzees and bonobos, which can only occasionally keep time to a metronome beat at preferred tempos and mostly reactively rather than predictively (Hattori et al., 2013; Large & Gray, 2015; Merker et al., 2009; Yu & Tomonaga, 2015). Similarly, macaques require intensive training to finger-tap to a a metronome, and even then synchronization quality is poor (Honing et al., 2012). Other relevant display behaviors among chimpanzees, such as tree buttress drumming (Eleuteri et al., 2022) and pant-hoot choruses (Fedurek et al., 2013), are not synchronized to a beat, and chimpanzees apparently lack the motivation for audiomotor SMS (Wilson & Cook, 2016).[xxxi] Most other animals are unable to even perceive a beat in music (Honing et al., 2018; Merchant et al., 2018). Finally, some insects, crabs, and amphibians can automatically generate collective, isochronous rhythmic signals (Néda et al., 2000; Strogatz, 2004), but these effects are not under direct cognitive control and are largely inflexible (Merchant & Honing, 2014). Overall, then, the combination of *capacity* and *proclivity* for flexible, social, audiomotor SMS appears phylogenetically unique to humans (Wilson & Cook, 2016).

What selection pressures could have produced this unique combination of traits? Let us return to the wedding celebration. Before the music started, Susan related in a relatively impersonal way to her workplace assistants and saw her in-laws as members of a distant cultural outgroup. After hours of dancing, these high-construal boundaries of role and group have given way to seeing her assistants as fellow human beings and incorporating the bride's family into her model of "us." All status roles such as "assistant" and "in-laws," of course, are subjunctive and depend on language. Zooming out, then, traits such as beat and meter perception may have emerged or coalesced via selection for solving problems inherent to symbol use and triadic cognition.[xxxii] One relevant problem domain would be coordinating tricky updates to distributed social priors during group-level transitions in social structure, such as at weddings or other initiation rites (Cross, 2009; Wood, 2021). Synchrony would ease collective transition to the new status roles or arrangements, reducing risk of confusion or conflict. Another problem domain could be counteracting the paradoxically centrifugal effects of language, which, although an important bonding mechanism (Dunbar, 2010), accentuates self-other divides and facilitates high construal,

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thus increasing social distance (Harvey, 2018; Knoblich & Sebanz, 2008).[xxxiii] That is, by assigning categorical statuses, language carves deep conceptual joints between different social roles and between subgroups (e.g., phratries, clans, or moieties), decreasing total within-group similarity and risking fission or splintering (Rappaport, 1999; Harvey, 2018; cf. Perlovsky, 2017). Accordingly, conflicts between members of different moieties or clans within a single tribe are common (e.g., Joshua, 2021; Roscoe, 2013). Synchrony's ability to bond people of any identity or background (Savage et al., 2021) would thus represent a functional adaptation not for social cohesion per se, but instead for addressing the biologically novel threats posed to fitness as individuals' social environments became more variegated, complexly structured, and diffuse (cf. Baumeister et al., 2016; Dunbar, 2010; Smaldino, 2014). This possibility dovetails with suggestions that music and language co-evolved to play complementary roles in human sociality (Brown, 2017; Harvey, 2018).

In this telling, synchrony would be an evolutionary adaptation not simply for social bonding, but *for anti-structure*. This possibility would account for the rarity of beat perception and SMS among nonhuman animals, contrasting with the species-typical motivation to synchronize to auditory beats in even infant humans (Cirelli et al., 2016; Kotz et al., 2018; Wilson & Cook, 2016). Namely, non-linguistic animals, lacking language and normative social structure, simply have little corresponding need for anti-structure. It makes sense that humans, on whom structure imposes a heavy psychological load and yet who need it to survive (e.g., Freud, 2018; Henrich, 2015), also boast a behavioral phenotype that transiently relaxes structure while strengthening personal bonds. Future investigations, for example in evolutionary modeling, could quantify the selection pressures and dynamics (such as multilevel, kin, individual-level, or niche construction processes) that might lead to species-specific synchrony mechanisms for solving adaptive problems of structure.

7.2. Limitations

No model represents reality without distorting it. One obvious limitation of RePS is that real-world synchrony in fact often occurs in contexts of exquisitely differentiated musical and dance ensembles. Drummers, dancers, and instrumentalists contribute distinct parts to the musical

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whole, which requires top-down and self-other control (Heggli et al., 2021; Novembre et al., 2016; Harry et al., 2023). Participants frequently take leader-follower roles in such ensembles (Chang et al., 2017; Jacoby et al., 2021). So isn't real-world music, where most synchrony actually happens, clearly a kind of complex joint action rather than the break from top-heavy self-control I have been depicting? Possibly, but note that rhythmic synchrony is only one possible feature of music (Mehr et al., 2019, Savage et al., 2015). Melodic and vocal features may be strongly differentiated by performer, but in almost every case musicians and dancers perform in time to the same overall beat. Real-world musical ensembles thus involve flexible, adaptive balance between integration and segregation of self and other, with metrical subdivisions enabling different participants to contribute distinctively timed parts to one overarching rhythm (Harry, 2023; Savage et al., 2021; Zhang et al., 2018; Sadaphal et al., 2025). All else being equal, the synchronized elements of any performance should push the needle toward integration even in highly structured ensembles.

Other aspects of social context also play an important role in shaping synchrony outcomes, raising another possible critique: synchrony sometimes enhances or toughens social boundaries. In the Nuremberg rallies, for instance, synchronized marching seems to have helped rigidify social boundaries and strengthen the Nazi hierarchy, leading to derogation of outgroups and destructive obedience to authorities (Brown & Volgsten, 2006; cf. Wiltermuth, 2012). Dovetailing with this observation, some researchers have argued that synchrony supports, and is possibly an adaptation for, coalition signaling *vis-à-vis* competing coalitions (Hagen & Bryant, 2003; Mehr et al., 2021). Subjects accordingly rate audio tracks of soldiers marching in rhythmic cadence as more physically formidable and cohesive than the sound of people walking out of sync (Fessler & Holbrook, 2016). So how can synchrony break down social boundaries and the priors that support them if it strengthens boundaries and signals competitive coalition strength?

The response is twofold. First, synchronized or cadence marching is distinguished by characteristic features such as exceptionally tight and repetitive synchronization; heavy, monotonous beat; and strong behavioral inhibition and control (McNeill, 1995). That is, cadence marching ratchets down contextual parameters such as rhythmic groove, syncopation, arousal, and expressiveness that contribute to disinhibition and its downstream effects (see **Figure 4**).[xxxiv]

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Second, cadence marching nevertheless clearly retains self-other blurring and consciousness-altering effects (McNeill, 1995). Indeed, self-other merging is strongest when synchrony is perfectly matched to a simple beat (Sadaphal et al., 2025). What this implies is that controlled, comparatively low-arousal forms of synchrony such as cadence marching may increase suggestibility while strongly enhancing the entitative boundaries around the marching unit, perhaps via mechanisms similar to those in slow-tempo trance rituals (Fessler & Holbrook, 2016; Kawai et al., 2017; Lakens et al., 2011; Wilson & Gos, 2019; Yang et al., 2025). In this way, cadence marching may serve authorities by rendering participants temporarily compliant and receptive to top-down messaging while weakening inter-individual boundaries. (These effects may mirror the view of psychedelic plasticity as a "super-placebo," which augments receptivity to cultural and even ideological input; Dupuis & Veissière, 2022). This would explain why few if any pro-authority cultural critics have turned their ire on marching displays, but frequently condemn expressive music and dance.[xxxv]

Another possible critique is that real-world music can and undoubtedly often does evoke high-construal representations, for example by evoking abstract imagery or contributing to rituals that refer to intangible values or ideas (cf. Margulis, 2026). When we hear an Elgar march, we may be swept up in mental imagery of stately grandeur or patriotism (or fear of jingoism). But again, synchrony itself should push the needle toward low-construal representations, while liberation from normal top-down constraints could allow the brain to explore or freely associate within the state space of high-level representations untethered to immediate experience (see Section 4.2). Thus, we might find ourselves daydreaming about distant scenes or recalling old memories even while dancing in abandon with others. Indeed, this relatively free exploration may be part and parcel of the weakening and potential revising of high-level beliefs during synchrony. Susan and the other guests might daydream about far-off places or become completely absorbed in the music, or both. Either way, the social priors that normally canalize their experience are relaxed.

7.3. Final Notes

This review has aimed to outline a model of synchrony as a means not only for achieving social cohesion, but for weakening top-heaviness and inducing plasticity in the social brain. RePS

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points to a function for which humans seem to have a particular need. We live in complex worlds of high-construal beliefs and boundaries that robustly constrain behavior, imposing long-term goals and limitations to enable complex joint action. These conventionally and normatively scaffolded joint actions scale up to the level of collective intentionality, or society-level coordination grounded on shared conventions and institutions (Tomasello, 2019). We do not acquire the priors that support these worlds in a Lockean way from the ground up; rather, they enter the top level of the processing hierarchy via language and other symbols. Daily life typically requires that these high-level priors remain precise and fairly inflexible so we can predict others' actions based on role and context while using active inference to live up to our own obligations. Yet we also periodically need to update or even replace these priors — often in coordination with others. Many other means of revising high-level social priors are possible, but synchrony is unique in leveraging the predictive brain to scale up to large groups while restricting attention to the subjective present, boosting bottom-up signaling in a context of tight social coordination. In other words, synchrony limits participants' ability to think in abstracts and shortens their spatial and temporal horizons, even as it makes their observable actions more locally predictable to themselves and each other. At the neurobiological level, the brain's operations are nudged toward entropy, annealing networks of established social beliefs to allow for rapid but enduring revision. The resulting anti-structural state relaxes over-learned assumptions about who belongs to the ingroup, who occupies what role, and where the self stands in regard to others. **Features 1-3** and, at more extreme levels, **Feature 4** are accounted for in this way, while **Feature 5** flows from their consequences. Beyond social cohesion, synchrony is ultimately a way of globally relaxing our models of self, other, and the social world.

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[i] This epigraph from the Daoist philosopher *Zhuangzi*'s chapter "Horses' Hoofs" expresses a critique of leaders who disturb the original human unity by imposing morals through music (which unifies) and ritual (which separates). Here, I use it only to highlight distinct functions of rhythm vs. formal ritual and language.

[ii] Possibly, synchrony has stronger effects on "hot" feelings of social bonding than on "cold" (reflective) cooperative decisions (Tarr & Dunbar, 2023). This explanation tracks well with the association between synchrony and low-level sensorimotor processing highlighted in this review.

[iii] Throughout this review, "top-down" refers to associative control processes in the brain that integrate abstract representations to predict and control lower-level behaviors and prioritize inputs, while "bottom-up" refers to sensory, proprioceptive, or interoceptive inputs as they are passed up the brain's processing hierarchy (Clark, 2013; Frith, 2023).

[iv] Thanks to an anonymous reviewer for suggesting a version of this definition.

[v] This conceptual illustration was also suggested by an anonymous reviewer.

[vi] Not all studies show negative effects on articulated task coordination from synchrony. In Valdesolo et al. (2010), in-phase entrainment helped coordination on a one-shot version of the labyrinth task used in Lang et al. (2016), while in von Zimmerman et al. (2016), chanting in unison led to better coordination on a computer game. However, in the latter study, game scenarios that required more decoupled behavior enjoyed no such boost in performance, suggesting that synchrony benefited only symmetric collaboration outcomes. In Valdesolo et al. (2010), the use of a one-shot labyrinth task suggests that the interpersonal attention elicited by synchrony benefitted dyadic performance on a single task, whereas the iterated design in Lang et al. (2016) allowed latent sensorimotor coupling to disrupt coordination.

[vii] This interpretation would seem to contradict the intuitive cooperation hypothesis (Rand et al., 2014), which proposes that unreflective decision-making leads to more cooperative behavior. However, recent studies have offered poor support for intuitive cooperation, with positive effects strongly dependent on context (Kvarven et al., 2025). At any rate, hierarchical predictive processing does not map cleanly onto dual-process models of cognition (Bellini-Leite, 2022).

[viii] This schematic organization is reflected in the hierarchical anatomical structure of the cortex (Badre & D'Esposito, 2007; Clark, 2013; Trope & Liberman, 2010).

[ix] Speculatively, this could be understood as a neurobiological rendering of the concept of world-to-mind direction of fit in the philosophy of language (cf. Searle, 1995).

[x] This compounding of responsibilities and roles helps account for the fact that neural signals of top-down cognitive control and alpha power increase through adolescence, as social prediction becomes more and more dependent on long-timescale planning (Başar & Güntekin, 2009; Pines et al., 2023).

[xi] It is no contradiction that the content of a high-level model may be coarse-grained but have high precision. For example, we might be very confident that a local election will occur on a certain date, but not about its outcome. The model's content is coarse grained but its precision is high.

[xii] The neural resonance model has sometimes been advanced as an alternative to predictive processing for beat perception, but entrained neural patterns are probably simply the basis for a low-level predictive model of the beat (Fiveash et al., 2023; Matthews et al., 2023; Palmer & Demos, 2022).

[xiii] This reading of rhythms as social signals may find support in the role of brain regions known to contribute to social cognition in processing small-timescale timing errors (Forster & Brown, 2011).

[xiv] This emphasis on temporal over spatial profiles for inputs reflects the general cortical association between auditory, motor, and temporal processing, whereas visual processing is associated with spatial analysis (Mahar et al., 1994). Thus, synchronization is generally more stable with auditory than visual rhythmic stimuli (Grahn et al., 2011; Patel, 2014).

[xv] Compare Evans-Pritchard: "Considerable latitude is allowed in variation of movement. Not everyone makes the same movements but they are all made to the same rhythm" (1928, p. 451).

[xvi] I am indebted to Peter Threstrup Waade for this insight.

[xvii] Additional neurohormonal mechanisms probably play a role here. For instance, nasal administration of oxytocin increases quantitative measures of synchrony during naturalistic dance (Josef et al., 2019) and also reduces self-other control (De Coster et al., 2014; Pfundmair et al., 2018).

[xviii] Cacioppo et al. (2014) described this region as the infraparietal lobule, with voxel coordinates largely overlapping TPJ in Fairhurst et al. (2013).

[xix] Of course, not everyone can see everyone else on the dance floor. Perhaps Susan experiences self-other blurring only with the small number of dancers in her visual field (Cross et al., 2019; Tarr et al., 2014)? Thanks to the

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dominance of auditory processing in synchrony (Burr et al., 2009; Cannon & Patel, 2021; Celma-Miralles et al., 2016), the answer is probably not. Although multisensory (auditory and visual) stimuli can improve SMS stability (Takehana et al., 2019), the role of auditory processing in SMS may partially account for the fact that even anti-phase synchronization (which does not produce a visual impression of matched movements) can evoke subjective self-other blurring in dyads, given that asymmetric visible actions and acoustic events equally coincide with the global (mean-field) rhythm (Cirelli et al. 2014; Farrera & Ramos-Fernández, 2022; Fujiwara et al., 2023; Heggli et al., 2019; Sullivan & Blacker, 2017).

[xx] Kwan et al. (2022) challenge the REBUS hypothesis by pointing to evidence that psychedelics suppress stimuli response in the mouse primary visual cortex (Michaiel et al., 2019), suggesting that bottom-up signaling is dampened, not augmented. However, other forms of bottom-up signaling may be more relevant, including interoceptive signals and endogenous signals from the limbic system (Carhart-Harris & Friston, 2019). Other studies find that activity in the human visual cortex is potentiated by psychedelics when eyes are closed and the resulting internally generated phenomena are experienced as "real," suggesting relaxed gating on endogenous bottom-up signals (de Araujo et al., 2011; Roseman et al., 2016).

[xxi] Nevertheless, exposure to music has been shown to increase serotonin levels in both animals and humans (Mavridis 2015; Mao et al., 2022; Moraes et al., 2018; Park et al., 2023; Speranza et al., 2022), and dance and dance therapy increase human blood serum serotonin levels (Lopez-Nieves & Jakobsche, 2022). Future research could usefully investigate the effects of synchrony on 5-HT2A receptor function.

[xxii] Rhythmic music is so implicitly linked with trance that researchers often simply note it without comment and without proposing mechanisms to explain it (e.g., Seligman and Kirmayer, 2008; Singh, 2018).

[xxiii] Compare St John, who argues that the heavy beats of electronic music during raves create "(a) timeless zone, a space of disorder and indeterminacy where dancers…are licensed to experiment with their *other selves*" (2006, p. 5-6; emphasis mine).

[xxiv] Caution is warranted in accepting this claim, given that a recent meta-analysis found pervasive evidence of bias and poor design in clinical studies of psychedelic anti-depressive effects (Hovmand et al., 2023). If therapeutic effects for psychedelics are shown to be reliable, though, we might expect synchrony to have analogous benefits.

[xxv] By this, I mean that rhythmic music enables participants of distinct group identities or roles to interact and coordinate despite incompatible high-level social priors; I am not making the narrower, more controversial claim that any particular feature of music such as rhythm or synchrony is a true "universal" in the sense of existing and functioning identically in all cultures (cf. Savage, in press; Savage et al., 2015). This claim is socio-cognitive, not biomusicological.

[xxvi] Compare again Evans-Pritchard: "(A)t a dance where the rules of social life are to some extent relaxed and people enjoy themselves without stint, there is always a danger of disruption and disintegration through egotistical tendencies" (1928, p. 453).

[xxvii] Gioia (2019, p. 416) notes that the East German secret police had a "maniacal obsession" with the danger the punk rock movement posed to Communist rule, hinting that this view is not simply a post-hoc interpretation.

[xxviii] Whether behavioral addiction is a neurobiologically valid concept is a hotly debated question (e.g., Billieux et al., 2015). I have no desire to wade into this controversy, but am only highlighting that some people do report compulsive urges to take part in dance and other synchrony-like activities that interfere with other pursuits.

[xxix] This hypothesis might seem to run aground on the fact that deficits in audiomotor synchronization are well documented among subjects with ASD (Yoo & Yoon, 2019). However, recent research suggests that these deficits result from problems with motor preparatory activity and neural synchronization rather than temporal prediction per se (Beker et al., 2021), and indeed ASD is often associated with heightened interest in music and musical aptitudes such as absolute pitch (Applewhite et al., 2022; Wenhart et al., 2019). People with ASD are perfectly capable of bottom-up attention capture by music and rhythm.

[xxx] A particularly illustrative example may be found in the annual Burning Man festival in Nevada, which prominently features electronic dance music and attracts attendees from Silicon Valley, which abundantly rewards individualism, opportunistic risk-taking, flexibility, and creativity: that is, "neo-forager" values (Richman, 2008).

[xxxi] One captive chimp was recorded spontaneously drumming on an upturned bucket with semi-regular beat patterns, but this behavior was apparently not intended for social purposes and did not elicit motor synchronization among other chimps (Dufour et al., 2015).

[xxxii] I do not wish to over-stress a strict adaptationist interpretation. As Savage et al. (2021) and others have argued, traits relevant for musicality may have emerged in part through cultural evolution operating on expressions of genetic adaptations for language such as audiomotor connectivity and precise timing ability. Gene-culture coevolution may also be implicated, given the important role of feedback from cultural inputs in the scenario I am suggesting (cf. Patel, 2021).

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[xxxiii] For instance, the acquisition of language during childhood is accompanied by a transition away from mirroring and interactional synchrony and toward complementary motor dynamics, such as turn-taking (Tomasello et al., 2005; Feldman, 2007; Rakoczy, 2008).

[xxxiv] This observation implies an additional empirical prediction: cadence marching will be comparatively less pleasurable than expressive rhythmic dancing when other factors are controlled (see **Figure 4**).

[xxxv] Synchronized, high-arousal, yet martial displays such as the Maori haka dance (Jackson & Hokowhitu, 2002) may provide an interesting contrast to both expressive dance and cadence marching. They seem to share with expressive dance a high arousal level, but their tight, choreographed synchronization allows little individual variation and so may track closer to marching. Plausibly, the haka's effects on group entitativity (and perceived formidability) would be more similar to those of cadence marching than to a dance party. Future research could explore these comparisons in relation to synchrony dimensions such as arousal level, timing precision, and in-phase vs. antiphase coordination.

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