Rhythm, synchrony, and cooperation

(Stage 1 Registered Report)

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Abstract:

Previous research suggests that synchronization is a key mechanism facilitating interpersonal cooperation, and rhythmic synchronization to a regular beat is a key feature distinguishing music from language. However, whether synchronization to a regular musical beat enhances cooperation relative to a linguistic control without a regular beat remains debated and has not yet been demonstrated experimentally. We will compare the effects of reciting familiar lyrics (“Twinkle, Twinkle, Little Star”) with and without synchronization to a musical beat on willingness to cooperate (as measured by a public goods game and by attitudinal self-report) for n=200 participants. The results of this Registered Report will provide evidence regarding the existence of causal relationships between music, language, synchrony, and cooperation. This will have important theoretical implications for understanding the origins of music and language, as well as practical implications regarding the use of music to enhance cooperation in contemporary society.

Keywords:

Music, language, cooperation, synchrony, rhythm

1. Introduction:

The evolutionary origins of cooperation and of music are two puzzles that have been debated since Darwin¹⁻⁴. The “music and social bonding” (MSB) hypothesis has suggested that these two puzzles may be related, in that musicality (the capacity to produce and perceive music) may have coevolved with cooperation⁵. In particular, synchronization to a regular beat is one of the aspects that most clearly distinguish music from language⁶⁻⁸, and growing experimental evidence suggests that synchronized movement in time with others causes people to behave more cooperatively⁹⁻²³.

However, there are two unresolved issues that we propose to address regarding the causal relationship between synchrony and cooperation: 1) published studies may be skewed by publication bias⁹, and 2) manipulations of synchrony have not directly compared music against linguistic controls. These issues are important because in the past high-profile claims

of the power of music, such as the so-called “Mozart effect”, were found to not be robust when tested with appropriate controls^{24–26}. Furthermore, while rhythmic synchronization to an isochronous (equal-timed) beat is a defining feature of most of the world’s music, languages around the world have their own sense of rhythmic structure that allows speakers to synchronize their speech to some extent even in the absence of an isochronous beat⁸. Because music shares so many similarities with language, understanding the evolutionary origins of and relationships between music, language, and cooperation requires understanding how similarities and differences between music and language affect cooperative behavior^{6,27,28}.

We propose to address the first issue by using the Registered Report format, in which experimental designs are accepted in principle for publication before results are known²⁹. We propose to address the second issue by using a between-subjects design that directly compares a condition with an isochronous beat to a control condition without an isochronous beat. In the isochronous condition, groups will recite lyrics simultaneously to an isochronous beat. In the linguistic control they will recite the lyrics simultaneously but without an isochronous beat (they will produce the same lyrics together, but in free rhythm rather than to a regular beat). Previous studies have yet to make such a controlled comparison: instead, most previous research either compares synchronization to a beat against a null control without simultaneous behavior, against asynchronous beats where different participants are assigned to different isochronous tempos, or against coordinated action where participants entrain to a shared beat but perform actions out of phase. None of these manipulations thus tests the crucial question of whether an isochronous beat independently facilitates cooperation via enhanced synchronization.

We have consciously chosen to propose this Registered Report using a novel experimental paradigm rather than attempting a direct replication of one of the many published studies regarding synchrony and cooperation. Whether previous studies would replicate is an important question, but to date although many experimental studies have conceptually replicated evidence that synchrony facilitates cooperation, no direct replication attempts have been published. One unpublished conference poster³⁰ failed to replicate the influential study by Wiltermuth & Heath¹⁶, but this replication attempt had limited power (n=27 participants). Furthermore, the specific task used (listening to the Canadian national anthem "Oh Canada") was only appropriate for a North American context, and is unlikely to generalize cross-culturally to our Japanese context. We believe that our attempt to conceptually replicate these findings by directly comparing conditions with vs. without an isochronous beat is a more valuable contribution than attempting a direct replication of any previous individual study.

1.1 Study aims and hypotheses:

The MSB hypothesis predicts that synchronization to a musical beat should enhance cooperation relative to a linguistic control. The present study aims to test this hypothesis by measuring participants’ cooperation following their participation in a group vocalization task. The independent variable is the presence of an isochronous beat (to facilitate synchronization), versus no beat. The dependent variable - cooperation- will be measured based on precedent in the literature using behavioral measures (via an economic public goods game) and self-report attitudinal measures (via an aggregated measure combining perceived trust, self-similarity, entitativity, and fusion).

The MSB hypothesis predicts that both behavioral and attitudinal measures of cooperation should be higher after recitation to an isochronous beat than without an isochronous beat. If

we find that cooperation after recitation to an isochronous beat is statistically equivalent to, or lower, than after recitation without a beat, this would support the null hypothesis that synchronization to an isochronous beat does not play a causal role in facilitating cooperation. Such a result would add evidence to proposals that argue that music may be an evolutionary byproduct of the evolution of cognitive capacities adapted for language processing^{6,28}. We emphasize that such a result would not conclusively validate such theories, as there are many other possible ways that music may have evolved besides the coevolution of isochronous beats and cooperative behavior^{31,32}.

It is difficult to do a fully controlled comparison of “music” vs. “language”, because music is generally performed simultaneously in groups using discrete pitches and a regular beat, while language is most commonly produced sequentially by individuals taking turns speaking one at a time without discrete pitches or a regular beat^{8,33,34}. To isolate the crucial factor of synchronization to an isochronous beat suggested as a mechanism by previous research, we need to make the musical condition less “musical” by using unpitched lyrics rather than discrete pitches, and make the language condition less “speech-like” by having participants speak the same lyrics simultaneously rather than sequentially, so the only difference between the two groups is the presence or absence of an isochronous beat to which participants can synchronize. Pilot experiments suggested that it is impossible to make the non-isochronous linguistic control completely “unsynchronized”. Instead, participants naturally quasi-synchronize their lyric recitation because, although language does not normally incorporate a fixed musical beat, it does contain its own inherent rhythmic structure⁶ (see demonstration videos below for examples of these pilot experiments). However, this quasi-synchronized simultaneous recitation is similar to naturally occurring situations such as group recitation of texts in classrooms or religious prayer. If synchronized recitation to an isochronous beat enhances cooperation more than such quasi-synchronized recitation without an isochronous beat, this would suggest that synchronization to an isochronous beat does indeed enhance cooperation relative to what is possible with non-isochronous linguistic rhythm alone. If not, that would suggest that any causal relationship between synchrony and cooperation is not due to the presence of a regular beat that has been previously proposed to be a key mechanism underlying such a relationship.

Hypotheses:

H1: simultaneous recitation of lyrics to an isochronous beat will increase **behavioral** measures of cooperation relative to a control condition with simultaneous recitation of lyrics without an isochronous beat

H2: simultaneous recitation of lyrics to an isochronous beat will increase **attitudinal** measures of cooperation relative to a control condition with simultaneous recitation of lyrics without an isochronous beat

2. Methods:

Research assistants (RAs) will manage recruitment and experimental debriefing, but experimental briefing and tasks will be conducted by pre-recorded video instructions to eliminate the possibility of experimenter expectancy effects⁹.

2.1 Independent variable

The independent variable is isochrony (isochronous beat vs. no isochronous beat). In a between-subject design, groups of four participants will be randomly assigned to either condition. In the no isochronous beat condition, groups will be asked to recite the lyrics of “Twinkle, Twinkle, Little Star” simultaneously but at their own pace without an audible metronome beat and without attempting to synchronize. In the isochronous beat condition, groups will be asked to recite the lyrics in synchrony to an isochronous metronome beat. In both conditions, participants will be asked to produce the lyrics without using discrete pitches (i.e., without melody). “Twinkle, Twinkle, Little Star” was chosen because it is one of the most widely sung songs across cultures, ages, and levels of musical expertise, and its use will allow this paradigm to be replicated cross-culturally and adapted to other features in future (e.g., melody, harmony, see Fig. 3 for examples). As the present study will initially be conducted in Japan, we use a well-known Japanese translation of the lyrics.

Each group will recite the lyrics three times while seated in a semi-circle around a monitor displaying the lyrics via an instructional video. The first time they will repeat each line of text sequentially after first hearing a sample vocalization demonstrated by an experimenter via prepared video. The second time they will produce the full lyrics together in tandem with the sample vocalization demonstration video. Finally, they will produce the full lyrics together without the sample vocalization. Videos of demonstration experiments are available here:

1) Isochronous beat:

<https://osf.io/3skmp/> (final time without sample vocalization)

<https://osf.io/8vjyf/> (full experiment video)

2) No isochronous beat:

<https://osf.io/u4gyd/> (final time without sample vocalization)

<https://osf.io/3edx5/> (full experiment video)

2.2 Dependent variables

2.2.1 Behavioral prosociality (Public goods game)

The dependent variable will be the amount contributed by each participant to a shared box in a one-off public goods game. Based on precedent^{16,22}, we will use a version of the public goods game in which participants each receive a starting sum of ¥1,000 (~\$US10). This is approximately 2.5 times that used in ref.²², because this is our institution’s standard reimbursement rate for experiments. Public goods games using real money are a good model of cooperation because unlike self-report questionnaires participants responses have tangible effects on themselves (they actually receive the money offered) and because they mimic the “tragedy of the commons” problem that is fundamental to real-life cooperation: all participants benefit when the group cooperates, but selfish individuals can maximize their own profits at the expense of the group³⁵.

After reciting the lyrics, each participant will receive ¥1,000 in coins (coin denominations will be: 1x¥500, 3x¥100, 3x¥50, and 5x¥10), and be asked to anonymously place any amount between 0-1000yen into an unlabeled envelope. One at a time, participants will leave the experiment room to post their envelopes into a "shared" box through a small hole in the lid. Participants are told that any money placed in the shared box will be doubled and re-distributed evenly between all participants in the group. The inside of the box will be padded so the presence or absence of coins will not be audible when the envelope is inserted.

Figure 1 shows sample payouts in the public goods game. The maximum any one participant could receive is ¥2,500 (~USD\$25). This would occur if they keep all ¥1,000 for themselves, but the other three participants each donate their ¥1,000 to the shared box, and this ¥3,000 was doubled (¥6,000) and then shared equally between all four participants (¥1,500 per participant). Conversely, the minimum a participant could receive would be ¥500 (~USD\$5), if they put all ¥1,000 into the shared box but all three of the other participants keep their ¥1,000yen for themselves, and the ¥1,000 in the shared box was doubled (¥2,000) and then distributed equally between all four participants (¥500 per participant).

Figure 1. Example public goods game payouts for four individuals who contribute initial amounts of ¥0, ¥300, ¥500, and ¥1000 and received final payouts of ¥1900, ¥1600, ¥1400, and ¥900 respectively.

Once all participants have inserted their envelopes, the amount of money will be counted by the RA, doubled, and, at the end of the experiment, redistributed to the four participants in envelopes. Other than the participants themselves, no one - including the RAs - will know exactly how much each other participant contributed, unless the other participants all contribute ¥1,000 or all contribute ¥0, in which case this will be obvious when the payout from the shared box is distributed.

Following the public goods game, they will complete a paper-based written questionnaire regarding their feelings when reciting the lyrics.

2.2.2 Attitudinal prosociality (self-report)

Attitudinal prosociality will be measured using the same variables as previous studies^{16,22}. Participants will answer a series of self-report questions:

- 1) Entitativity: "How much did you feel you were on the same team with the other participants?" (7-point Likert scale)
- 2) Perceived similarity: "How similar do you think you are to the other participants?" (7-point Likert scale)

- 227 3) Trust: “How much did you trust the other participants going into the group
228 investment exercise?” (7-point Likert scale)
229 4) Interdependent self-construal (“Inclusion of self in other” [IOS]): “how close do you
230 currently feel to all the people you just did the activities with?” (indicating which of a
231 series of 7 increasingly overlapping circles best described their judgment).

232 Previous research has not consistently found that one of these variables is a superior measure
233 of attitudinal prosociality. To avoid issues involving multiple comparisons, we will therefore
234 combine these four variables into a single joint measurement of attitudinal prosociality. Our
235 pilot analysis found an acceptable level of internal consistency (Cronbach’s alpha = 0.7 when
236 including all four variables, which was higher than when excluding any of the variables).
237 Therefore, we will use the mean of all four 7-point scales as our dependent variable for
238 attitudinal prosociality.

240 2.2.3 Exploratory variables

241 In order to aid post-hoc interpretation of results, we will also measure the following variables
242 (adapted from refs.^{12,22}).

- 243 1) Perceived difficulty of the movement activity: ““how difficult was the group task” ”
244 (7-point Likert scale)
245 2) Enjoyment: “how enjoyable was the group task?” (7-point Likert scale)
246 3) Embarrassment: “How uncomfortable or embarrassed did you feel during the group
247 task?” (7-point Likert scale)
248 4) Prior familiarity with other participants: “do you know any of the other participants in
249 the group (i.e. have you seen or met them before): 0 = no, I know none of them; 1 = I
250 know one; 2 = I know 2; 3 = I know them all. If participants answer that they know
251 one or more participants, they will then answer the following question for each known
252 participant: “how well did you know this participant before the study?” (5- point
253 Likert scale from 1 (I had never seen him/her before) to 5 (I know him/her very well).
254 5) Instruction following: “I followed the instructions for reciting the lyrics well” (7-point
255 Likert scale from “strongly disagree” to “strongly agree”)
256 6) Perceived synchronization: “My recitation was synchronized with the other
257 participants” (7-point Likert scale from “strongly disagree” to “strongly agree”)
258 7) Sex: “What is your sex?” (“female”, “male”, “other”)
259 8) Age: “How old are you?” (numeric)
260 9) Native language: “What is your native language?” (free response)
261 10) Musicianship: “How many years of formal musical training have you had?” (numeric)
262 11) General comments: “Do you have any comments regarding the lyric recitation, public
263 goods game, questionnaire, or other aspects of the study?” (free response)
264

265 2.3 Statistical analyses

266
267 To test our predictions, we will follow previous research in performing t-tests of both
268 behavioral and attitudinal prosociality between the conditions with and without
269 synchronization to a musical beat^{9,16}. We predict that both of these tests will show greater
270 prosociality in the isochronous condition, but have included tests for both because previous
271 meta-analyses have suggested the possibility that only attitudinal prosociality effects are
272 robust⁹. Because we are testing two predictions, we will use a Bonferroni correction to
273 maintain an overall Type-1 Error alpha level of .05 (i.e., the critical significance p-value for
274 each t-test will be set to .025).
275

If the analyses shows that one or both measures are not significantly greater in the predicted direction, we will then use equivalence testing³⁶ to determine whether the dependent variables can be considered to be significantly equivalent (i.e., differences are small enough to be effectively non-existent). These equivalence tests will assume the same alpha level and smallest effect size of interest parameters as our primary analyses (i.e., $\alpha = .025$, range of effect sizes considered equivalent = -0.4 to 0.4). Analysis code for the significance tests to be performed (two t-tests and two equivalence tests in case the t-test is non-significant) has been tested and is included in the analysis scripts, but we do not report the resulting p-values for the pilot data because they cannot be meaningfully interpreted until the full experiments have been completed.

We note that the statistical assumptions underlying t-tests are likely not to hold because pilot data suggests that participants tend to allocate money rounded to multiples of ¥100, because minimum/maximum contributions of ¥0/¥1000 are common, and because participants interact in groups of four. However, alternative tests available (e.g., multilevel modeling, nonparametric tests) would not resolve all of these issues and, unlike t-tests, are not yet easily conducive to equivalence testing. We believe that the large number of participants and groups we plan to collect ($n=200$ participants from 50 groups) will be sufficient to mitigate the effects of violations of statistical assumptions.

Analysis scripts in R³⁷ and the accompanying pilot data are available at <https://github.com/compmusiclab/rhythm-coop/>.

2.4 Power analysis

A priori power analysis requires estimating the effect size before collecting data, which is notoriously difficult³⁸. A previous meta-analyses found estimated effect sizes (Hedges' g) of 0.49 for attitudinal prosociality and 0.45 for behavioral prosociality⁹. However, meta-analyses are likely to overestimate effect sizes because publication bias means that studies (other than Registered Reports) with small, non-significant effect sizes are unlikely to be published. Given such uncertainty, some recommend calculating power analyses assuming an effect size of 0.4 as an approximation of the "smallest effect size of interest"³⁸.

Assuming a smallest effect size of interest of 0.4, power of 80%, and an alpha level of 0.025 (one-tailed; see above for rationale), we will require at least 100 participants per condition, which corresponds to 25 groups of 4 participants per condition ($n=200$ participants total for two conditions).

2.5 Sample

Japanese-speaking participants aged 18 years or older will be recruited from Keio University and the surrounding communities through a combination of social media, printed flyers, and word-of-mouth advertisement. To avoid demand effects, the study will be advertised as being about "music and language" without mentioning synchronization or cooperation. The amount of money participants will be compensated will range from ¥500-¥2500 (~USD\$5-25), depending on the strategies for the public goods game chosen by them and the other participants in their group. Participants will be recruited in blocks of 16, from which they will be randomly assigned into groups of four, each of which will be randomly assigned into one of the two conditions until we have collected at least enough usable data for each condition as determined by the power analysis. RAs will recruit participants, distribute and collect

experimental materials, and start the video with experiment instructions, but will leave the room during the experiment and will not answer questions during the experiment to avoid influencing participants. The only time during the experiment that RAs will interact with participants is once the participants have put money in the shared box, after which RAs will distribute self-report questionnaires. After participants have completed the questionnaires the experiment will be over, after which RAs will distribute the money and debrief participants, including explaining the purpose of the experiment.

No Japanese-speaking participants over 18 will be excluded unless there are irregularities during the experiment (e.g., if a participant changes their mind about participating or fails to complete all experimental tasks, as determined by verbal self-report or questionnaire responses). Previous studies have sometimes excluded participants who knew each other well²², but we will instead aim to reduce any potential effects of familiarity by randomizing participant assignment to groups and will ask participants to rate their degree of familiarity with any others in the group.

2.6 Pilot data/positive controls:

We have conducted pilot experiments with students from our research seminar to ensure that our measures do not suffer from floor/ceiling effects and show enough variability to allow us to measure an effect if it exists. Figure 2 shows pilot data for our confirmatory dependent variables of behavioral and attitudinal prosociality in the conditions with and without an isochronous beat. Interestingly, these pilot data display a reverse pattern to the meta-analysis of Rennung et al.: there appears to be a suggestive effect of isochronous beat on behavioral prosociality (Hedge's $g = 0.77$ is above our “smallest effect size of interest” of 0.45), while attitudinal prosociality shows only a very weak effect size that is opposite to the predicted direction (Hedge's $g = -0.15$).

Figure 2. Violin plots of the effect of isochronous beat on behavioral and attitudinal prosociality for $n=32$ participants in a pilot experiment. Behavioral prosociality (left) is measured as the amount of money contributed in the public goods game (¥0-¥1000) and attitudinal prosociality (right) is the mean of four different 1-7 Likert scales for trust, entitativity, perceived similarity, and interdependent self-construal. Large dots indicate

individual participant data points, small dots indicate mean values, and error bars indicate 95% confidence intervals.

Exploratory analysis of the four individual attitudinal variables that were combined to form our average attitudinal prosociality variables showed that perceived trust appeared to suggest the predicted increase in the beat condition ($g = 0.37$), but perceived similarity and interdependent self-construal appeared to suggest the opposite effects ($g = -0.42$ and $g = -0.29$, respectively), while perceived entitativity appeared to show almost no effect in either direction ($g=0.12$). The exploratory dependent variables did not show any suggestive differences between conditions except that the condition with an isochronous beat seemed to be perceived as somewhat more embarrassing than without an isochronous beat ($g = 0.6$; see Fig. S1 for full results of exploratory analyses).

Prior to collecting pilot data from these 32 participants, we also collected pilot data for other conditions of future interest: passive control, rhythm + melody, rhythm + melody + dance, and rhythm + melody + dance + harmony (Fig. 3). These pilot data for six groups of four participants each suggest that this experimental design produces sufficient variability in our behavioral dependent variable to allow for the detection of an effect if it exists, and suggest that our proposed design can be usefully applied for future experiments attempting to investigate potential independent effects of melody, harmony, lyrics, and dance on cooperation in addition to the effect of rhythm investigated in the present study. These pilot data do not support our predicted effect - in fact, they show the opposite effect, with greater behavioral prosociality in the condition without an isochronous beat ("2. lyrics") than with an isochronous beat ("3. rhythm"). However, we suspect that this result is likely attributable to the very limited sample size of only four participants per condition. We also note that these earlier pilot experiments did not use pre-recorded videos and more generally were not as well-controlled as the later experiments reported in Figure 2, so the data should be treated as a preliminary proof of concept.

Figure 3. Pilot data for behavioral prosociality across 6 conditions intended to progressively isolate five different musical features that may facilitate cooperation: lyrics, rhythm, melody, dance, and harmony. The current manuscript only focuses on conditions 2 and 3 to isolate the role of rhythms using isochronous beats, but these data are shown to illustrate the potential of this paradigm to be expanded in future studies. Dots indicate individual participant points ($n = 24$).

Table 1 | Registered Report design planner (from <https://osf.io/93znh/>)

Question	Hypothesis	Sampling plan	Analysis Plan	Interpretation given
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		(e.g. power analysis)		different outcomes
Does rhythmic synchronization facilitate cooperation?	H1: simultaneous recitation of lyrics to an isochronous beat will increase behavioral measures of cooperation relative to a control condition with simultaneous recitation of lyrics without an isochronous beat	Power analysis: n=100 participants x 2 conditions (d $\geq$ 0.4, β = .8)	Between-sample t-test of amount contributed to public goods game (α = .025, one-tailed). Equivalence testing if non-significant (α = .025, -0.4 > d $\leq$ 0.4)	Significant t-test: synchronization to an isochronous beat facilitates behavioral cooperation. Significant equivalence test: synchronization to an isochronous beat does not facilitate behavioral cooperation. Neither test significant: Inconclusive.
(Same as above)	H2: simultaneous recitation of lyrics to an isochronous beat will increase attitudinal measures of cooperation relative to a control condition with simultaneous recitation of lyrics without an isochronous beat	(Same as above)	Same as above but for mean of 4 attitudinal variables (Section 2.2.2)	Significant t-test: synchronization to an isochronous beat facilitates attitudinal cooperation. Significant equivalence test: synchronization to an isochronous beat does not facilitate attitudinal cooperation. Neither test significant: Inconclusive.

Ethics:

Permission to perform this study was granted by the Keio University Shonan Fujisawa Campus Institutional Review Board (IRB no. 229) to PES. All pilot participants provided informed consent and all future participants will provide informed consent.

Data/code availability: Pilot data, protocols, and stimuli (including demonstration videos of pilot experiments) are available at <https://osf.io/jskxa/>. Analysis code is available at <https://github.com/compmusiclab/rhythm-coop/>.

Authors' contributions:

Conceptualization: PES, BT, SF, KY, MY, MH

Investigation: MY, MH [collected pilot data]

Analysis: PES, MY

Writing – original draft: PES, MY, MH

Writing – reviewing/editing: BT, SF, KY

Project administration/supervision/funding acquisition: PES

Competing interests. We declare we have no competing interests.

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References:

1. Darwin, C. *The descent of man, and selection in relation to sex*. (John Murray, 1871).
2. Honing, H., Cate, C., Peretz, I. & Trehub, S. E. Without it no music: Cognition,

- biology and evolution of musicality. *Philos. Trans. R. Soc. B Biol. Sci.* **370**, 1–8 (2015).
3. Ravignani, A., Delgado, T. & Kirby, S. Musical evolution in the lab exhibits rhythmic universals. *Nat. Hum. Behav.* **1**, (2016).
4. Nature Human Behaviour Editors. The cooperative human. *Nat. Hum. Behav.* **2**, 427–428 (2018).
5. Savage, P. E. *et al.* Music as a coevolved system for social bonding. (Under revision)
6. Patel, A. D. *Music, language and the brain*. (Oxford University Press, 2008).
7. Fitch, W. T. The biology and evolution of music: A comparative perspective. *Cognition* **100**, 173–215 (2006).
8. Savage, P. E., Brown, S., Sakai, E. & Currie, T. E. Statistical universals reveal the structures and functions of human music. *Proc. Natl. Acad. Sci. U. S. A.* **112**, 8987–8992 (2015).
9. Rennung, M. & Göritz, A. S. Prosocial consequences of interpersonal synchrony: A meta-analysis. *Z. Psychol.* **224**, 168–189 (2016).
10. Mogan, R., Fischer, R. & Bulbulia, J. A. To be in synchrony or not? A meta-analysis of synchrony's effects on behavior, perception, cognition and affect. *J. Exp. Soc. Psychol.* **72**, 13–20 (2017).
11. Tarr, B., Launay, J., Cohen, E. & Dunbar, R. Synchrony and exertion during dance independently raise pain threshold and encourage social bonding. *Biol. Lett.* **11**, 1–4 (2015).
12. Tarr, B., Launay, J. & Dunbar, R. I. M. Silent disco: Dancing in synchrony leads to elevated pain thresholds and social closeness. *Evol. Hum. Behav.* **37**, 343–349 (2016).
13. Lang, M., Bahna, V., Shaver, J. H., Reddish, P. & Xygalatas, D. Sync to link: Endorphin-mediated synchrony effects on cooperation. *Biol. Psychol.* **127**, 191–197 (2017).
14. Cirelli, L. K., Einarson, K. M. & Trainor, L. J. Interpersonal synchrony increases prosocial behavior in infants. *Dev. Sci.* **17**, 1003–1011 (2014).
15. Rabinowitch, T. C. & Meltzoff, A. N. Synchronized movement experience enhances peer cooperation in preschool children. *J. Exp. Child Psychol.* **160**, 21–32 (2017).
16. Wiltermuth, S. S. & Heath, C. Synchrony and cooperation. *Psychol. Sci.* **20**, 1–5 (2009).
17. Hove, M. J. & Risen, J. L. It's all in the timing: Interpersonal synchrony increases affiliation. *Soc. Cogn.* **27**, 949–960 (2009).
18. Miles, L. K., Nind, L. K. & Macrae, C. N. The rhythm of rapport: Interpersonal synchrony and social perception. *J. Exp. Soc. Psychol.* **45**, 585–589 (2009).
19. Lakens, D. & Stel, M. If they move in sync, they must feel in sync: Movement synchrony leads to attributions of rapport and entitativity. *Soc. Cogn.* **29**, 1–14 (2011).
20. Kokal, I., Engel, A., Kirschner, S. & Keysers, C. Synchronized drumming enhances activity in the caudate and facilitates prosocial commitment - If the rhythm comes easily. *PLoS One* **6**, e27272 (2011).
21. Valdesolo, P. & DeSteno, D. Synchrony and the social tuning of compassion. *Emotion* **11**, 262–266 (2011).
22. Reddish, P., Fischer, R. & Bulbulia, J. Let's dance together: Synchrony, shared intentionality and cooperation. *PLoS One* **8**, 1–13 (2013).
23. Launay, J., Dean, R. T. & Bailes, F. Synchronization can influence trust following virtual interaction. *Exp. Psychol.* **60**, 53–63 (2013).
24. Rauscher, F. H., Shaw, G. L. & Ky, K. N. Music and spatial task performance. *Nature* **365**, 611 (1993).
25. Thompson, W. F., Schellenberg, E. G. & Husain, G. Arousal, mood, and the Mozart effect. *Psychol. Sci.* **12**, 248–251 (2001).

- 477 26. Mehr, S. A., Schachner, A., Katz, R. C. & Spelke, E. S. Two randomized trials provide
478 no consistent evidence for nonmusical cognitive benefits of brief preschool music
479 enrichment. *PLoS One* **8**, e82007 (2013).
- 480 27. Brown, S. A joint prosodic origin of language and music. *Front. Psychol.* **8**, 1–20
481 (2017).
- 482 28. Pinker, S. *How the mind works*. (Norton, 1997).
- 483 29. Nature Human Behaviour Editors. What science looks like. *Nat. Hum. Behav.* **3**, 763
484 (2019).
- 485 30. Schachner, A. & Garvin, L. Does synchrony really affect social variables? *Proc. 11th*
486 *Int. Conf. Music Percept. Cogn. (ICMPC 11)* (2010).
487 https://madlab.ucsd.edu/pdfs/Schachner_ICMPC_Poster_2010.pdf
- 488 31. Honing, H. Ed. *The origins of musicality*. (MIT Press, 2018).
- 489 32. Wallin, N., Merker, B., & Brown, S., eds. *The origins of music*. (MIT Press, 2000).
- 490 33. Fujii, S. & Wan, C. Y. The role of rhythm in speech and language rehabilitation: The
491 SEP hypothesis. *Front. Hum. Neurosci.* **8**, 1–15 (2014).
- 492 34. Harmon-Jones, C. K. Does musical behaviour affect affiliation? (PhD diss, Texas
493 A&M University, 2011).
494 [http://oaktrust.library.tamu.edu/bitstream/handle/1969.1/ETD-TAMU-2011-08-](http://oaktrust.library.tamu.edu/bitstream/handle/1969.1/ETD-TAMU-2011-08-10045/HARMON-JONES-DISSERTATION.pdf?sequence=2)
495 [10045/HARMON-JONES-DISSERTATION.pdf?sequence=2](http://oaktrust.library.tamu.edu/bitstream/handle/1969.1/ETD-TAMU-2011-08-10045/HARMON-JONES-DISSERTATION.pdf?sequence=2)
- 496 35. Hauert, C., Holmes, M. & Doebeli, M. Evolutionary games and population dynamics:
497 Maintenance of cooperation in public goods games. *Proc. R. Soc. B Biol. Sci.* **273**,
498 2565–2570 (2006).
- 499 36. Lakens, D. Equivalence tests: A practical primer for t tests, correlations, and meta-
500 analyses. *Soc. Psychol. Personal. Sci.* **8**, 355–362 (2017).
- 501 37. R Core Team. R: A language and environment for statistical computing. (2017).
502 <https://www.r-project.org/>
- 503 38. Brysbaert, M. How many participants do we have to include in properly powered
504 experiments? A tutorial of power analysis with reference tables. *J. Cogn.* **2**, 1–38
505 (2019).

Figure S1. Results of pilot experiments from $n=32$ participants reported in Figure 2 for individual confirmatory variables (prior to averaging) and for individual exploratory variables. See Methods for details regarding individual variables. Note that one participant included spoke English, not Japanese, as a native language. This participant was included in the pilot data for simplicity, but when collecting and reporting future data participants who are non-native Japanese speakers will be excluded.

S1. Pilot experiments with alternative versions of the no isochronous beat condition.

In addition to the no isochronous beat condition used for collecting pilot data, we experimented with two alternative versions of this condition: alternating and staggered. The alternating approach attempted to be more analogous to language by having participants alternate lines rather than recite them together simultaneously (i.e., participant 1 says “twinkle twinkle little star”, then participant 2 says “how I wonder what you are”, etc.). However, we decided that this was not an appropriate comparison because it differed in two ways from the isochronous beat condition (no isochronous beat and alternating rather than simultaneous).

The staggered approach attempted to prevent participants from synchronizing their texts using the natural rhythms of language by asking each participant to stagger the time they began reciting the lyrics by waiting for a short period after the previous participant began

reciting to begin their own recitation. However, we decided that this condition was less appropriate than the non-staggered version used to collect our pilot data because it failed to isolate whether there was any unique value for facilitating cooperation in an isochronous musical beat compared to the rhythms naturally present in non-isochronous spoken language.

Videos of these pilot experiments can be viewed at the following links:

- 1) No-beat (alternating): <https://osf.io/sdku8/>
- 2) No-beat (staggered): <https://osf.io/9ny7r/>