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Research Report

Joint music listening enhances interpersonal affective and neural synchrony

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ABSTRACT

Music is one of the most pleasurable stimuli in humans' life, often experienced in social contexts where shared enjoyment can amplify emotional responses. Despite its significance, the neural and affective mechanisms underlying socially shared music remain largely unexplored. Using hyperscanning fNIRS, we examined shared musical pleasure in friend dyads (N = 34) who listened to favorite and experimenter-selected music either alone or together. Joint listening did not increase pleasure in general, but slightly enhanced pleasure for friend's music and increased Pleasure Similarity, defined as the correlation of continuous pleasure ratings within dyads. Musical pleasure was associated to heightened activity in the prefrontal cortex, particularly in the joint condition. In the joint (*vs* solo) condition, Interpersonal Neural Synchrony (INS) was greater, and significantly predicted by Pleasure Similarity. These findings reveal the neural dynamics of shared musical pleasure, emphasizing the important role of social sharing in modulating music-induced reward processing.

1. Introduction

Music is an inherently social stimulus that fosters synchronization and likely evolved to enhance social bonding and group cohesion among humans (Freeman, 1998; Koelsch, 2013; Savage et al., 2021; Tarr, Launay, & Dunbar, 2014). This intrinsic social component is hypothesized to be tightly related to the emotional power of music (Nummenmaa, Putkinen, & Sams, 2021). Music represents one of the earliest and most accessible forms of interpersonal interaction, universally used to engage infants (Nguyen et al., 2025) and to effectively regulate their emotional state (Hilton et al., 2022; Nguyen, Flaten, Trainor, & Novembre, 2023; Trehub, 2019;

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Trehub, Ghazban, & Corbeil, 2015). Over the lifespan, the ability of music to induce and regulate emotions and moods is a primary motivation for engaging with it, both individually and in social settings (Saarikallio, 2011; Saarikallio & Erkkilä, 2007; Schäfer & Sedlmeier, 2010). During social activities, such as concerts or ceremonies, music has been shown to promote the alignment of emotions and associated physiological responses among audiences (Ardizzi, Calbi, Tavaglione, Umiltà, & Gallese, 2020; Czepiel et al., 2021; Kragness et al., 2023; Rai et al., 2024; Tschacher et al., 2023), which in turn is promoting social cohesion (Cheong, Molani, Sadhukha, & Chang, 2023; Durkheim, 2016; Reddish, Tong, Jong, Lanman, & Whitehouse, 2016). These experiences contribute to fulfill humans' innate need for social connection, which is crucial for overall well-being (Cacioppo & Patrick, 2008; Holt-Lunstad, Smith, Baker, Harris, & Stephenson, 2015). During the COVID-19 pandemic crisis, music emerged as an essential means of fostering social connection, enabling individuals to share emotional experiences despite physical distance, notably with balcony concerts and online live streams (Greenberg, Decety, & Gordon, 2021; Groarke, MacCormac, McKenna-Plumley, & Graham-Wisener, 2022; Levstek, Barnby, Pocock, & Banerjee, 2021; Ferreri et al., 2021). Increased engagement in music-related activities during lockdown correlated with lower self-reported depressive symptoms among participants, mediated by reward-related mechanisms (Mas-Herrero et al., 2023). Both music experience and social situations are considered higher order, abstract rewards, which are engaging remarkably overlapping areas in the brain, with a main role played by the mesolimbic dopaminergic system (Berridge, 2007; Blood & Zatorre, 2001; Nummenmaa et al., 2021). Other systems, such as oxytocin and opioid transmissions, are also involved in both music experience and social behavior (Harvey, 2020; Mas-Herrero et al., 2023; Menon & Neumann, 2023; Ooishi, Mukai, Watanabe, Kawato, & Kashino, 2017; Putnam & Chang, 2022).

Intense feeling of pleasure in responses to music have been associated to the activation of regions related to reward, including the caudate nucleus, the ventral tegmental area, and the prefrontal cortex (PFC; Blood & Zatorre, 2001; Salimpoor, Benovoy, Larcher, Dagher, & Zatorre, 2011; Salimpoor & Zatorre, 2013). Reward responses have been increased or decreased by up- and down-regulating the dopaminergic reward system through the stimulation of the dorsolateral PFC (DLPFC, Mas-Herrero, Dagher, & Zatorre, 2018) or by manipulating the dopaminergic transmission (Ferreri et al., 2019), leading to increased and decreased reward responses. These findings have thus supported the causal implication of the mesolimbic reward circuitry in musical pleasure.

Research in social neuroscience has demonstrated that simply being aware of sharing an emotional experience (i.e., observing emotional pictures) with a friend, even without direct interaction, can intensify the emotional experience and more strongly activate reward-related brain areas compared to experiencing the emotion alone (Wagner et al., 2015). This effect is further modulated by the closeness of the relationship (Fareri & Delgado, 2014). Accordingly, reward system implication, reflected in ventral striatum or PFC activations, has been found in joint attention tasks as well as during shared emotional experiences (such as watching videos or movies together) in dyadic settings (Hirsch, Zhang, Noah, & Bhattacharya, 2023; Nummenmaa et al., 2012). The question thus raises of whether musical pleasure might be modulated by the social sharing of musical experiences, and if so, via which underlying mechanisms. Current findings for this modulation measured behaviorally are mixed.

While Liljeström, Juslin, and Västfjäll (2013) found that listening to self- or experimenter-selected music with close friends or partners heightened the intensity of emotional responses, other studies reported no significant differences in affective responses, such as the occurrence of chills, between group listening and solo listening conditions (Egermann et al., 2011; Sutherland et al., 2009). Group listening sessions with predominantly unfamiliar individuals resulted even in diminished pleasure responses compared to solo listening (Curzel, Carraturo, Ripollés, & Ferreri, 2023), while shared online music listening with multiple participants without interactive engagement, increased perceived pleasure responses, with greater reported pleasure with increasing number of participants sharing the listening (Curzel, Osiurak, et al., 2024).

These mixed results may be due to varying experimental settings, which can affect the degree of closeness within the dyad or group (Chung, Grèzes, & Pacherie, 2024), and/or employing different kinds of music, with preferred and familiar songs being likely more effective at modulating pleasure responses than unfamiliar ones (Zatorre, 2015). Additionally, none of these studies has examined whether sharing music listening influenced affective synchronization among the participants (i.e., as expressed by similar emotional responses, see also Chabin, Gabriel, Comte, Haffen, et al., 2022), nor investigated the neural underpinnings of shared affective musical experience. To investigate this, an experimental setting should allow for analyzing music social processes from a real-time relational perspective in ecological contexts (*second-person neuroscience*, Schilbach et al., 2013), and using different types of controlled music materials (e.g., varying in familiarity or liking). Studies in social neuroscience have employed the simultaneous monitoring of multiple brains (i.e., hyperscanning, Montague et al., 2002) to compute the Interpersonal Neural Synchrony (INS) representing the coherence or synchronization between the brain activities of multiple individuals (Czeszumski et al., 2020). In the realm of neuroscience research investigating music processing, increased INS has been related to cooperative singing (Osaka et al., 2015), joint music making (Abalde, Rigby, Keller, & Novembre, 2024), song learning (Pan, Novembre, Song, Li, & Hu, 2018), synchronized drumming (Liu, Duan, Dai, Pelowski, & Zhu, 2021), as well as musical pleasure similarity between audience members during live concerts (Chabin, Gabriel, Comte, Haffen, et al., 2022; Chabin, Gabriel, Comte, & Pazart, 2022).

Based on this evidence, our present study used a hyperscanning functional Near-InfraRed Spectroscopy (fNIRS; see Curzel, Tillmann, and Ferreri (2024) for a review) approach to investigate whether musical pleasure can be modulated by the social sharing of listening to different types of music, and if yes, via which underlying neural mechanisms.

To this aim, 34 pairs of friends listened to their favorite and experimenter-selected music under two conditions: alone (solo) and together (joint; see Fig. 1). Friends were selected to promote INS, influenced by the quality of relationships (Kinreich, Djalovski, Kraus, Louzoun, & Feldman, 2017; Ma & Liu, 2024), and to make the experience more reflective of real–life interactions, thus reducing feelings of strangeness (Koul, Ahmar, Iannetti, & Novembre, 2023). In both conditions, participants were exposed to the same stimuli as their friend. During music listening, participants continuously reported their levels of felt pleasure. Within each dyad, we computed correlations between continuous pleasure ratings as a measure of Pleasure Similarity. To investigate the neural underpinnings, we concurrently measured the oxygenation of the PFC of each participant of the pair by using two 22-channel fNIRS wireless systems, and computed their PFC functional activity and INS.

2. Methods

2.1. Participants

Thirty-four pairs of friends (68 healthy participants; 55 women, 3 nonbinary gender, mean age: 21.4 ± 3.6 years–age range: 18–33 years) were recruited via social networks advertisements and flyers distributed around the university campus. Pairs of friends were composed both by individuals of the same gender ($n = 27$), and by individuals of different genders (see Fig. S1, A, $n = 7$). Relationship closeness within the dyads had a mean score of 4.03 ± 1.57 on a 1-to-7 scale (where 1 = distant and 7 = very close; Inclusion of Other in the Self scale, IOS, Aron, Aron, & Smollan, 1992). All participants reported normal or corrected to normal vision and no history of neurological and/or psychiatric disorders. Among them, 55 participants were non-musicians, 17 were amateur musicians, and 1 was an expert musician (further details about musicianship can be found in Fig. S1, B). During pre-experiment assessments, participants reported to generally like pop music (i.e., the style selected for the experiment; see Fig. S1, C), and a list of 12 favorite songs, which were used for the selection of music stimuli (see the Section 2.2. for more details). Individual differences in sensitivity to music reward were assessed using the extended version of the Barcelona Music Reward Questionnaire (eBMRQ, Cardona et al., 2022), and empathy traits, both in cognitive and affective components, with the Interpersonal Reactivity Index (IRI, Davis, 2011).

Participant took part in the experiment voluntarily, signed a written informed consent prior participation, and received a monetary reward after the participation. The study protocol was approved by the research ethics committee of the University of Lyon (notice n° 2023-01-12-004). The study was anonymous and followed the Helsinki Declaration, Convention of the Council of Europe on Human Rights and Biomedicine.

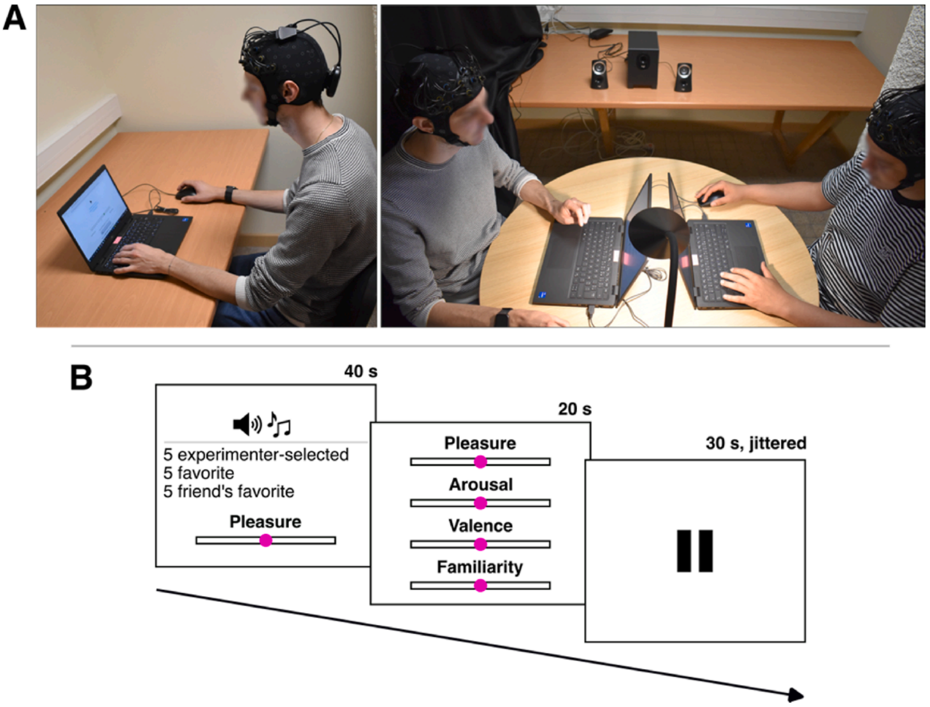

Fig. 1 – Experimental setting and paradigm. A) Experimental setting: selected dyads of participants listened to music alone (solo condition) or together (joint condition). In both conditions, music was played through speakers. B) Schematic representation of the experimental paradigm. In each condition, participants listened to 5 own's favorite, 5 friend's favorite, 5 experimenter-selected songs lasting 40 sec each. During listening participants provided *continuous* ratings of pleasure and, after each song, overall pleasure, among other affective measures. Subsequently, participants were instructed to watch the screen and not communicate (neither verbally nor non-verbally) during a 30 sec ± 5 sec jittered pause.

2.2. Music stimuli

The music stimuli comprised experimenter-selected songs and self-selected favorite songs. The experimenter-selected songs consisted of pop music. Songs were selected using the web application “Sort Your Music” (http://sortyourmusic.playlistmachinery.com/index.html) by checking each song's scores for various musical attributes, notably tempo (i.e., beats per minute), energy (i.e., arousal), valence, and popularity. Songs with high values of popularity were excluded from the selection. Four playlists, each comprising 5 songs, were then created and balanced based on their musical attributes. Two playlists were utilized during the listening phase of the study, while the other two playlists were reserved for a memory phase (not detailed in this paper). An analysis of variance (ANOVA) was performed for each musical attribute to ensure that their mean score was not significantly different between playlists (see Table S1 and S2). The playlists were then counterbalanced across experimental conditions.

Favorite songs comprised songs indicated by the participants during the pre-experiment assessment. For each song, participants provided the exact timing in seconds corresponding to their favorite moments in each song. Two playlists of 5 favorite songs each were created for each participant, balanced for musical attributes, and following the same procedure used for experimenter-selected songs. To prevent dyads of participants from hearing the same song twice, the number of titles listed by participants (i.e., 12) exceeded the songs used in the experiment.

Each original song was trimmed to a 40 sec excerpt, normalized in loudness to a maximum value of -1dB, with 5 sec of exponential fade-in and fade-out. Experimenter-selected songs’ excerpts always comprised a part of the verse and the chorus. The music stimuli were prepared using Audacity, version 3.1.3.

2.3. fNIRS data acquisition

Two continuous wave fNIRS systems (MK-II, Artinis Medical Systems, The Netherlands), equipped with 10 LED light sources (emitting light at 757 and 843 nm) and 8 detectors, were used to measure the cortical activity of participants. The prefrontal cortex (PFC) was selected for monitoring due to its relevance in research related to 1) social interaction tasks (frequently monitored in hyperscanning paradigms together with the temporoparietal junction; Babiloni & Astolfi, 2014; Gvirts & Perlmutter, 2020; Redcay & Schilbach, 2019); 2) music cognition (Curzel, Tillmann, & Ferreri, 2024), musical pleasure (Mas-Herrero et al., 2018), and aesthetic judgements (Cattaneo, Lega, Flexas, et al., 2014; Cattaneo, Lega, Gardelli, et al., 2014; Ferrari, Lega, Tamietto, Nadal, & Cattaneo, 2015). Optodes (i.e., sources and detectors) placement and array design were performed with AtlasViewer (Aasted et al., 2015), resulting in 22 channels and 2 short-separation channels. Optodes were anchored in a dark, soft fabric headcap (2.55 mm neoprene; Artinis Medical Systems headcap) and positioned with reference to the 10/20 international system (Klem, Lüders, Jasper, & Elger, 1999). Prior to acquiring data, the coupling between optodes and scalp was optimized by manually relocating hair falling between the two.

fNIRS signal was recorded at a sampling frequency of 50.0 Hz. The synchronization of the two fNIRS devices and the two computers, used for collecting behavioral data, was achieved through the lab streaming layer (LSL) system.[1]

2.3.1. Precise optodes localization with smartphone photogrammetry

To improve the anatomical precision of the optodes array, smartphone-based photogrammetry (Mazzonetto, Castellaro, Cooper, & Brigadoi, 2022) was applied on a different group of 10 participants (7 women, mean head circumference 56.00 ± 2.53 cm; for further information refer to Table S3). Initially, the fNIRS headcap was fitted over participants' head using 10/20 international system (Klem et al., 1999) landmarks. Subsequently, colored faux-optodes (with green indicating detectors, and red indicating sources) were inserted into the caps' optodes holders. 360° videos of participants' head (lasting 106.8 ± 12.2 sec) were captured using an Asus phone's camera in portrait mode, with HD resolution (1080p, 30 frame per second). A custom Python script was created to:

1) Reconstruct a virtual 3D model of participants' heads (i.e., a mesh) on Agisoft Metashape© using image frames extracted at a rate of 1 frame per second from recorded videos.
2) Identify and isolate the nodes of points forming landmarks (such as Nasion, Inion, Cz, left and right preauricular points) and optodes using a manually defined HSV (Hue, Saturation, Value) color scale range.
3) Cluster the identified points and estimate the optode position as the centre of mass of each cluster.
4) Perform an affine registration using the least squared method to transpose the measured coordinates on a reference atlas based on the MNI 152 template (Mazzonetto et al., 2022).
5) Extract the MNI coordinates of each participant's optodes and landmarks.
6) Cluster the MNI coordinates of all participants and find the centre of mass of each cluster, defining the mean coordinates for clustered optodes and landmarks.

The coordinates extracted using this method (detailed in Table S4) were then employed to update the coordinates within each participant's '.snirf' file within the group that participated in the full experiment, and were projected onto a virtual brain model (refer to Fig. 2, B). The mean channel length measured was 30.3 ± 1.2 mm, while the mean short-separation channel length was 11.8 ± .4 mm. All length measurements are detailed in Table S5. For enhanced signal analysis robustness, the channels were categorized into 4 symmetrical Regions of Interest (ROI), designed as right/left dorsolateral PFC (r/lDLPFC) and right/left medial PFC (r/lMPFC; see Fig. 2, B).

2.4. Procedure

The study was designed with the goal of conducting both functional hemodynamic response analysis and INS analysis. The setting was that of a hyperscanning study (i.e., the

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[1] https://github.com/sccn/labstreaminglayer.

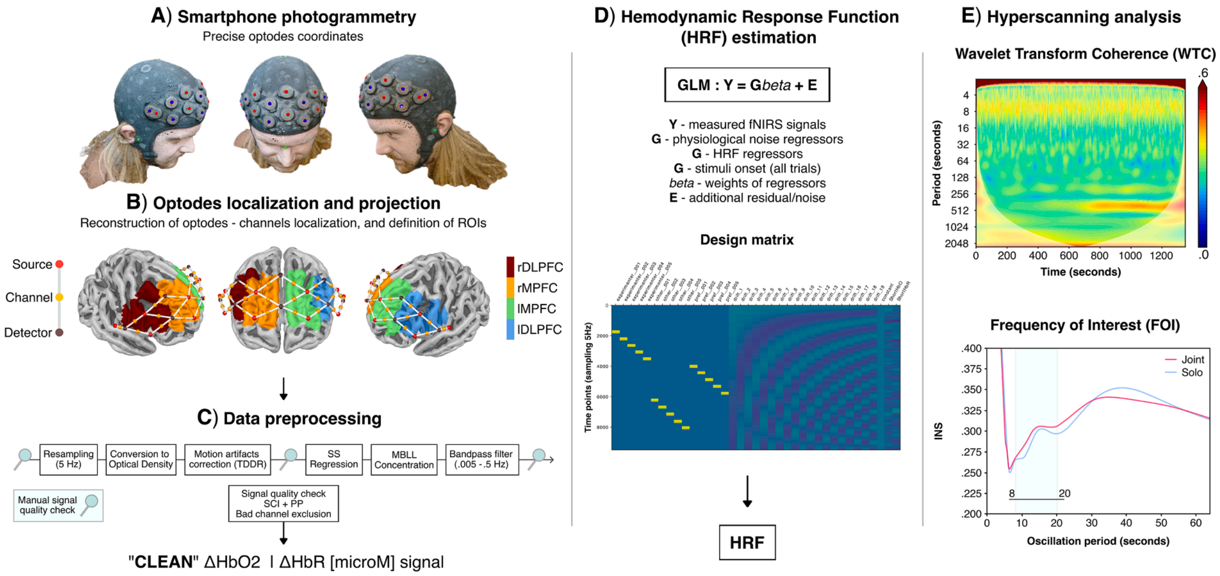

Fig. 2 — fNIRS methodological pipeline. A) Smartphone photogrammetry was applied to gain spatial resolution; B) The obtained MNI coordinates were projected on a virtual brain and the fNIRS array was divided in 4 ROIs; C) fNIRS raw signal was preprocessed, removing physiological noise and motion artifacts. Bad channels were excluded by using SCI and PP values, and signal quality was manually checked along the procedure; D) Hemodynamic Response Function estimation was conducted by applying a GLM, whose design matrix is reported. E) Hyperscanning analyses employed WTC on the preprocessed signal (homologous channels within each dyad) and the Frequency of Interest was identified by plotting INS scores with oscillation periods (see Section 2.6.3.).

simultaneous recording of two brains' activity; Montague et al., 2002) embedding two main experimental conditions. These consisted of listening to music alone (solo condition) or together (joint condition). The order of the conditions was counterbalanced across dyads. Prior to the start of the experimental procedure, a wireless fNIRS system (see Section 2.3. for more details) was installed on participants' heads. In the solo condition, participants were seated alone in a quiet room, in front of a laptop equipped with a speaker (Logitech Z313®). In the joint condition, dyads of participants sat face-to-face on opposite sides of a table about 1 m apart in another quiet room, both with a laptop and with a speaker on a fixed side of the room (see Fig. 1, A). The rooms used were counterbalanced across conditions, and the experimenters remained outside the room during the experiment. The performed task was identical in both conditions. However, during the solo condition, the participants were unaware of what their companion was doing.

At the beginning of the experimental session, participants could adjust the volume of the speaker at a comfortable level. The task was structured with a sequence of 40 sec of music listening, followed by 20 sec of questions about the musical stimuli, and a 30-sec (± 5 sec, jittered) pause. This sequence was repeated for a total of 15 musical stimuli, comprising 5 experimenter-selected songs, followed by 5 favorite songs of one participant and 5 favorite songs of the other participant (see Section 2.2. for more details). Just before each playlist of 5 songs was played, participants were notified about its content (i.e., which Song Category: Experimenter-selected, Favorite, Friend's favorite). Throughout each musical stimulus, participants were asked to continuously indicate the pleasure they were experiencing by moving a slider on a scale from 0 to 100 (with 100 representing the maximum pleasure; sampled at 2 Hz). Additionally, they were prompted to report any experience of chills by pressing the space bar for the entire duration of each chill. Following each stimulus, participants answered four questions using a 0 to 100 scale (0 representing the negative or minimum limit and 100 representing the positive or maximum limit), notably to judge the overall pleasure felt, followed by ratings of valence, arousal, and familiarity of the stimuli. After these judgments, participants were asked to indicate their level of concentration on a scale from 0 to 100, and then they were given the opportunity to leave comments about the experience. In the joint condition, participants could move, look at each other and communicate non-verbally only when they were listening to music. After the completion of the task in the joint condition, participants rated also their feeling of connection (with a 0–100 scale) and the level of closeness in the relationship (IOS scale, Aron et al., 1992) with their friend.

2.5. *Statistical analyses*

2.5.1. *Behavioral data*

2.5.1.1. PLEASURE. Descriptive analyses of the pleasure ratings were conducted to assess their distributional properties. *Overall* pleasure ratings (i.e., provided *after* listening to each musical excerpt) exhibited a skewness of −1.01 and a kurtosis of 3.60, indicating a moderate negative skew and a moderately leptokurtic distribution. *Continuous* pleasure ratings (i.e., the mean of pleasure ratings provided *during* listening each musical excerpt) showed a skewness of −.55 and a kurtosis of 2.90, reflecting a slight negative skew and a mildly platykurtic distribution. These results suggest only modest deviations from normality. Linear Mixed Models (LMMs), which are known to be robust to such moderate deviations from normality (Schielzeth et al., 2020), were then used to predict both continuous and overall pleasure ratings. These models incorporated random intercepts and slopes for the Social Condition (i.e., solo, joint) nested within subjects, capturing individual variability in both baseline levels and the effect of the Social Condition. To account for variability related to the musical stimuli, we also included Song ID as a random effect. Song ID was defined based on the experimental design: experimenter-selected songs, which were presented to multiple dyads, were assigned a unique identifier for each song, while participant-selected favorite songs were assigned a single identifier per dyad, collapsing across own and friend's favorites. This choice reflects the dyad-specific and jointly experienced nature of favorite songs and allows stimulus-related variance to be modeled directly while maintaining a parsimonious random-effects structure. The computed models included Social Condition and Song Category (i.e., own's and friend's favorite songs, and experimenter-selected songs), testing both their fixed effects and interactions. All models were fitted using restricted maximum likelihood estimation. To ensure model convergence, we used the *bobyqa* optimizer with an increased number of iterations. Type 3 Wald chi-squared tests were used to evaluate the statistical significance of fixed and interaction effects. Both marginal ($R^2_{(m)}$) and conditional ($R^2_{(c)}$) R^2 values were used as indicators of the goodness-of-fit for the models. $R^2_{(m)}$ quantifies the proportion of variance explained by the fixed factors, while $R^2_{(c)}$ accounts for the proportion of variance explained by both fixed and random factors. The intra-class correlation coefficient (ICC) was calculated to quantify the proportion of total variance in pleasure ratings attributable to clustering in the data (i.e., between-subject and between-song variability). To avoid eventual multicollinearity issues among the fixed effects predictors in LMM models, numerical predictors were scaled. Post-hoc Tukey-corrected pairwise comparisons were conducted following significant effects. The analyses were carried out using the lme4, emmeans, lmtest, car packages in R (version 3.3.0).

2.5.1.2. Pleasure similarity in dyads. Continuous pleasure ratings were used to compute scores of Pleasure Similarity. Specifically, a Pearson correlation was applied to the time-series of continuous pleasure ratings for each song within each participant dyad. Correlation values were first transformed into correlation distances using the formula: *correlation distance* = 1 - *correlation value*. These distances were then inverted to compute Pleasure Similarity scores using the formula *Pleasure Similarity* = 2 - *correlation distance*, ensuring that higher scores reflected greater similarity.

A descriptive scatter plot (Fig. 3, C) was created for assessing the relationship between the mean of continuous pleasure ratings for each song (x-axis) and the score of pleasure similarity (y-axis), divided by dyad.

Pleasure Similarity was compared across Social Conditions and Song Categories using the same statistical analyses as described in Section 2.5.1.1., except for having the factor “Dyads” replacing “Subjects” in random effects. Since Pleasure Similarity represents a shared score, the Song Categories of one's own favorite songs and the friend's favorite songs were automatically combined into a single category of favorite songs.

2.6. *Neural data*

Prior to analyses, the recorded fNIRS signal was preprocessed (see Fig. 2, **C**). This included assessing signal quality, removing extracortical and physiological noise (e.g., cardiac pulsations, respiration frequency, components of light absorbed by other tissues), and correcting for motion artifacts.

Successively, the analysis of the preprocessed fNIRS data was structured along two main axes, aiming to compute, across conditions and song categories, i) the Hemodynamic Response Function (HRF; see Fig. 2, **D**), and ii) the Interpersonal Neural Synchrony (INS, see Fig. 2, **E**), namely assessing synchronization in phase and amplitude across time and frequency between homologous channels within each dyad of participants. Preprocessing and HRF calculation were performed using the MNE-NIRS toolbox (version .6.0; Gramfort, 2013; Luke et al., 2021), integrated with MNE (version 1.6.1; Gramfort, 2013), and the Nilearn package (version .10.3; Nilearn contributors, 2024).

2.6.1. *Preprocessing of fNIRS data*

Raw intensity data were downsampled to 5.0 Hz and converted to optical density (i.e., light attenuation changes). Motion artifacts in the signal were corrected by applying the Temporal Derivative Distribution Repair (TDDR) method (Fishburn, Ludlum, Vaidya, & Medvedev, 2019), which uses an iterative-reweighting approach that does not necessitate the input of any specific parameters.

A first qualitative visual inspection of channels' quality was performed. The mean signal recorded by the two short separation channels was regressed from other channels, to remove physiological and extracortical noise contamination.[2] Successively, data were converted into HbO_2 and HbR concentration values (μM) using the modified Beer–Lambert law with a differential pathlength factor of 6.0 (Scholkmann & Wolf, 2013). A bandpass filter with cut-off frequencies of .5 and .005 Hz was applied to remove other physiological high frequency noise and slow drifts in the signal. An in-depth signal quality assessment was performed with the QT-NIRS toolbox (Montero-Hernandez & Pollonini, 2023; Pollonini, Bortfeld, & Oghalai, 2016). This allowed for the computation of the Scalp Coupling Index (SCI; Pollonini et al., 2014) and the Peak Spectral Power (PSP; Pollonini et al., 2016) for each measurement in each channel. These indices quantify the strength of cardiac pulsation in temporal and spectral domains, respectively. The scores derived from SCI and PSP are then combined to generate a Quality Assessment score (QA),

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[2] The short separation channels regression was performed at this stage only for data that were further used in the INS analysis. Alternatively, short separation channels were employed as regressors in the general linear model for estimating the Hemodynamic Response Function (HRF).

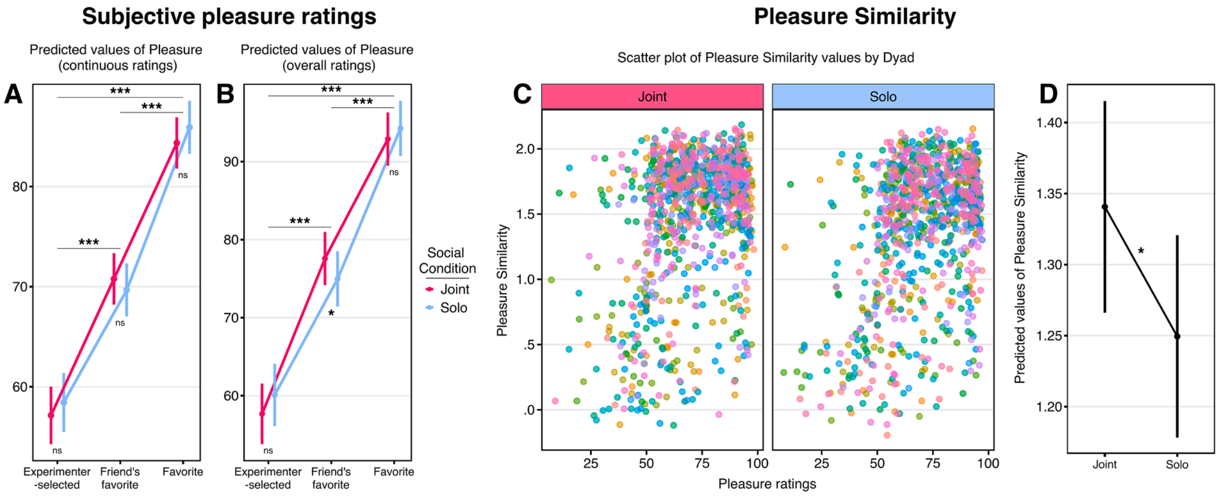

Fig. 3 — Predicted values of Pleasure and Pleasure Similarity. A) *Continuous* Pleasure ratings were significantly predicted by Song Category, with the highest pleasure reported for participants' own favorite songs, followed by friends' favorite songs, and lastly, experimenter-selected songs; B) Predicted ratings of *Overall* Pleasure showed the same effect as described in A), but showed also that the friend's favorite songs elicited significantly higher pleasure in the joint condition. C) Scatterplot displaying the distribution of Continuous Pleasure ratings in relation to Pleasure Similarity values, categorized by dyads, which are represented by different colored dots. D) Predicted values of Pleasure Similarity were higher in the joint condition. Shown here is the main effect of Social Condition. In A), B), D) mean values with 95% CI bars are reported for each Social Condition and Song Category. ns = non-significant; $*p < .05$; $***p < .001$.

which serves as a robust marker of potential residual noise in the signal. All channels with a QA score <.5 were excluded (see Table S6 for details). An average of 3.1 ± 4.4 channels per subject (including short-separation channels) were excluded in the solo condition, while 6.7 ± 6.2 channels per subject in the joint condition. ROIs for each subject that contained fewer than three good quality channels (QA > .5) were excluded. This step ensured a more robust signal representation for each ROI. A repeated visual signal quality inspection was conducted to confirm the effectiveness of the preprocessing procedure.

2.6.2. *Hemodynamic Response Function estimation*

A general linear model approach was applied to the preprocessed data to obtain the mean hemodynamic response to each musical stimuli across different experimental conditions.

The HRF was modelled using a double-gamma SPM model (Lindquist, Meng Loh, Atlas, & Wager, 2009) as basis function within the interval between the onset and the end of the stimulus. The design matrix comprised regressors for each trial within each distinct stimulus category, utilizing the Least Squares-All method (Rissman, Gazzaley, & D'Esposito, 2004), along with the mean signal obtained from the short separation channels as a non-interested regressor (Gagnon et al., 2011). This approach was employed to effectively account for the variability between stimuli within each stimulus category (refer to the Section 2.2. for further details) and to remove physiological and systemic noise. We also included a cosine drift model with components up to the high pass parameter value (.005 Hz). The mean values of both ΔHbO_2 and ΔHbR, representing the mean hemodynamic response during the stimulus period (40 sec), were computed for each participant, channel, and trial, and subsequently used for statistical analyses. A 3D descriptive brain map including ΔHbO_2 values divided by Song Categories was generated (see Fig. 4, A).

ΔHbO_2 is the most commonly used measure for assessing hemodynamic responses with fNIRS, as it positively correlates with the fMRI BOLD response (Kinder et al., 2022). ΔHbR is less used because it has smaller signal-to-noise ratio and amplitude, leading to a lower statistical power than ΔHbO_2.

Data were analyzed using linear mixed modelling to predict hemodynamic concentration values, specifically ΔHbO_2 and ΔHbR. Random intercepts and slopes for the Social Condition nested within participants were included, capturing individual variability in both baseline levels and the effect of the Social Condition. Additionally, random intercepts were included for each fNIRS channel and for Song ID, accounting for differences in baseline activity across channels and musical stimuli. As presented above, the model incorporated three predictor variables: Social Condition, Song Category, and ROI. Both their fixed effects and interactions were tested.

To better ensure an eventual direct relationship between the hemodynamic response and the pleasure experienced by participants, two additional models were computed by using respectively *continuous* pleasure and *overall* pleasure as predictors replacing Song Category. Pleasure ratings (both *continuous* and *overall*) were standardized (mean-centered and scaled by one standard deviation) before inclusion in the model to allow for standardized coefficient interpretation.

In all the tested models, the statistical analyses as described in Section 2.5.1.1. were applied. Post-hoc analyses were performed for significant effects and were Tukey-corrected.

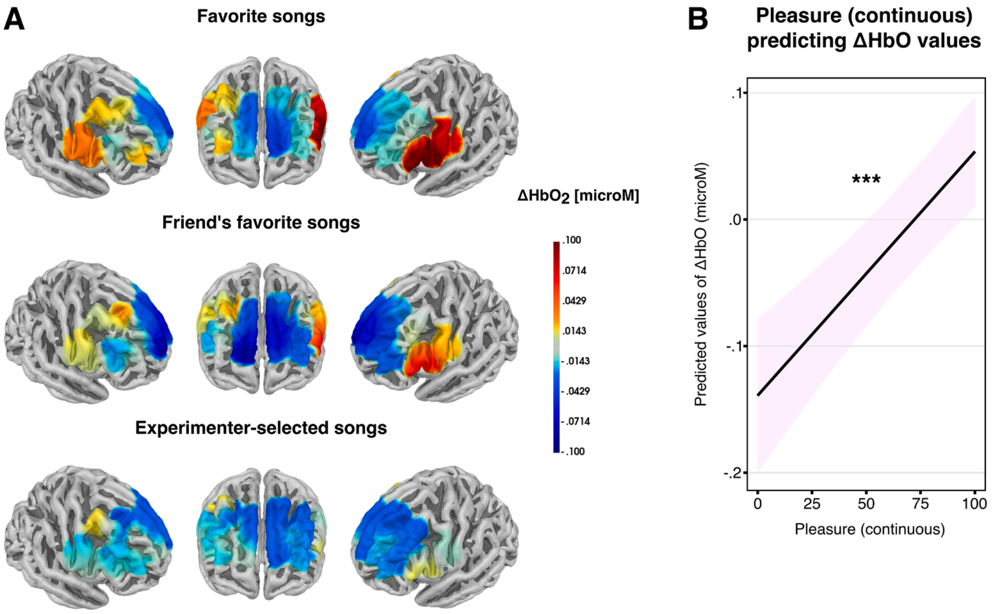

Fig. 4 – Values of ΔHbO_2 projected on a virtual brain and predicted by pleasure ratings. A) Mean values of ΔHbO_2 projected on a virtual brain; B) Predicted values of ΔHbO_2 over the entire PFC are positively predicted by *Continuous* Pleasure ratings. Shaded areas represent 95% confidence intervals. ******p* < .001.

2.6.3. *Interpersonal Neural Synchrony*

Interpersonal neural synchrony was computed on ΔHbO_2 and ΔHbR preprocessed concentration values of dyad's homologous channels. The coherence between the time series of each homologous channels' ΔHbO_2 and ΔHbR concentration values in a dyad was estimated with the Wavelet Transform Coherence (WTC), which represents the most commonly used method to compute interpersonal neural synchrony (Czeszumski et al., 2020). Specifically, it allows assessing the relation between two time series as a function of time and frequency (Grinsted, Moore, & Jevrejeva, 2004). The values included in this calculation ranged from the first pause before the initial stimuli and the last pause after the final stimuli (see Fig. 1, B). WTC was applied using the cross wavelet and the wavelet Matlab packages by Grinstead[3] (Chang & Glover, 2010; Grinsted et al., 2004). The calculated coherence values are referred to as *Interpersonal Neural Synchrony* (INS; Long et al., 2021; Nguyen, Schleihauf, et al., 2021).

Values outside the cone of influence, representing a region in the time-frequency domain where edge effects or artifacts due to the finite limits of the time series manifest, were excluded from the WTC analysis (white spaces in the graph quadrant in Fig. 2, E). The selection of a frequency of interest, or a band of frequencies (or periods), in which the neural coherence values could reasonably encompass the investigated phenomenon of interpersonal neural synchrony, currently lacks a systematic and standardized procedure in the literature (Kostorz et al., 2023; Nguyen, Hoehl, & Vrtička, 2021). To ensure objectivity and data-driven decision-making, we based this selection on two main assumptions: (1) The period, representing the duration of one complete cycle of oscillation of the frequency of interest, should ideally be shorter than the duration of a stimulus or epoch (i.e., less than 40 sec, which, when transposed into frequency, would be less than .025 Hz). Additionally, it should avoid coinciding with oscillations of potential residual physiological noises, such as respiration at approximately .3 Hz and cardiac pulsations at approximately 1.0 Hz. It is worth noting that fNIRS allows the monitoring of hemodynamic response, which typically takes about 3–5 sec to reach its peak (i.e., .2–.3 Hz). (2) A coherent oscillation occurring with a period shorter than 40 sec should be observed by plotting the mean coherence values of all channels together on the y-axis and frequency values on the x-axis. We thus expected observing a potential peak, which could represent the spectral range of interest (see Fig. 2, E). Following this approach, we plotted the mean neural coherence values for each social condition. A peak was identified, falling within a period range of 8–20 sec, which was subsequently chosen as our frequency range of interest. A second peak falling around 40 sec was evocative of the paradigm temporal structure, i.e., it likely represented the periodic onset of the auditory stimuli, and was therefore not included in the frequency of interest. An average neural coherence value was then calculated in this frequency range for each pair of homologous channels, for each stimulus.

Values of neural coherence were predicted using linear mixed modelling. The included predictor variables were Social Condition, Pleasure Similarity, and ROI. Pleasure Similarity scores were standardized (mean-centered and scaled by one standard deviation) before inclusion in the model to allow for

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[3] http://grinsted.github.io/wavelet-coherence/.

standardized coefficient interpretation. Random intercepts and slopes for Social Condition nested within dyads were included, together with random intercepts for fNIRS channels and Song ID, to account for variability associated with measurement channels and musical stimuli. The same statistical analyses as described in Section 2.5.1.1. were applied.

3. Results

3.1. *Behavioral results*

3.1.1. *Subjective Pleasure was partially enhanced by the joint condition*

To investigate how song category and joint (versus solo) listening influenced subjective pleasure responses, we applied a linear mixed model (LMM; see Section 2.5. for details): Pleasure ~ Social Condition * Song Category + (1 + Social Condition | Subject) + (1 | Song ID). The model predicting *Continuous* Pleasure responses ($\chi^2(1) = 1521.10$, $p < .001$; $R^2_{(m)} = .374$, $R^2_{(c)} = .588$, ICC = .34) revealed a significant main effect of Song Category (see Fig. 3, A; $\chi^2(2) = 410.67$, $p < .001$), confirming that the highest pleasure ratings were provided for one's own favorite songs (mean = 85.2; 95% CI [82.7, 87.6]), compared to friend's favorite songs (mean = 70.3; 95% CI [67.8, 72.7], t(1874) = 23.39, Tukey-corrected $p < .001$; Cohen's d = 1.27), and experimenter-selected songs (mean = 57.8; 95% CI [55.1, 60.6], t(45) = 19.02, Tukey-corrected $p < .001$; Cohen's d = 2.33). Friend's favorite songs were rated also significantly more pleasurable than experimenter-selected songs (t(45) = 8.65, Tukey-corrected $p < .001$; Cohen's d = 1.06). Neither Social Condition, nor the interaction with Song Category produced a significant effect (all ps > .073). The model predicting *Overall* Pleasure ratings ($\chi^2(1) = 847.97$, $p < .001$; $R^2_{(m)} = .350$, $R^2_{(c)} = .558$, ICC = .32), confirmed a significant main effect of Song Category ($\chi^2(2) = 324.14$, $p < .001$), indicating the same tendency of pleasure ratings as the precedent model on continuous pleasure ratings. In this case too, Social Condition fell short of reaching significance ($p = .054$). Additionally, the interaction between Song Category and Social Condition was significant (see Fig. 3, B; $\chi^2(2) = 9.34$, $p = .009$). Post-hoc tests revealed that the main effect of Song Category was consistent across Social Conditions (all ps < .001), with pleasure ratings on friend's favorite songs being higher in the joint condition (mean = 77.6; 95% CI [74.2, 81.0]), than in the solo condition (mean = 75.0; 95% CI [71.4, 78.5], t(451) = 2.08, Tukey-corrected $p = .038$; Cohen's d = .16). Other comparisons did not reach significance (all ps > .055).

3.1.2. *Increased Pleasure Similarity in the joint (vs solo) condition*

Pleasure Similarity scores were employed as a measure of the similarity of pleasure over time within the dyad and were derived from the correlation between *Continuous* Pleasure ratings collected during perception of each song. Fig. 3, C illustrates the distribution of Pleasure Similarity scores across conditions, showing increased similarity being associated with high pleasure levels in both conditions. To examine the potential modulation of Pleasure Similarity by Song Category and Social Condition, we applied the same LMM as used for the subjective (Continuous or Overall) Pleasure responses (see Section 2.5.1.1.). The model ($\chi^2(1) = 645.06$, $p < .001$; $R^2_{(m)} = .045$, $R^2_{(c)} = .235$, ICC = .20) revealed both a significant main effect of Social Condition (see Fig. 3, D; $\chi^2(1) = 5.33$, $p = .021$) and a significant main effect of Song Category ($\chi^2(2) = 16.46$, $p < .001$), but their interaction was not significant ($p = .621$). Similarity scores measured on favorite songs (including both one's own favorite song and the friend's one, see Methods' Section 2.5.1.2. for details) were significantly higher (mean = 1.52; 95% CI [1.46, 1.59]), compared to scores on experimenter-selected songs (mean = 1.30; 95% CI [1.20, 1.39], t(44) = 4.77, Tukey-corrected $p < .001$; Cohen's d = .49). Interestingly and more importantly, Pleasure Similarity was significantly higher in the joint condition (mean = 1.48; 95% CI [1.39, 1.56]), than in the solo condition (mean = 1.42; 95% CI [1.34, 1.49], t(32) = 2.35, Tukey-corrected $p = .025$; Cohen's d = .14).

3.2. *fNIRS results*

3.2.1. *Favorite songs increased DLPFC activity, in particular during joint listening*

We measured ΔHbO_2 and ΔHbR hemodynamic responses[4] over the PFC (Fig. 2, **A**) to identify cortical correlates of pleasure elicited by the shared (or not) music listening. We divided the fNIRS measurement template into four bilateral Regions of Interest (ROIs; Fig. 2, **B**). This allowed us to specifically monitor left and right DLPFC and medial PFC (MPFC) contributions, enhance signal reliability and minimize data loss when individual channels were excluded due to poor signal quality. ΔHbO_2 was the main metric in this analysis (but see Supplemental Information for ΔHbR, which usually produces weaker statistical outcomes; Kinder et al., 2022). A LMM was applied using ROIs, Social Condition and Song Category, as predictors: ΔHbO_2 or ΔHbR ~ Social Condition * ROI * Song Category + (1 + Social Condition | Subject) + (1 | Song ID) + (1 | Channel). The model predicting ΔHbO_2 concentration values ($\chi^2(1) = 2.13$, $p = .144$; $R^2_{(m)} = .008$, $R^2_{(c)} = .113$, ICC = .11), revealed a significant main effect of Song Category ($\chi^2(2) = 31.30$, $p < .001$), showing a significantly higher activity across the entire PFC for favorite songs (mean $\Delta HbO_2 = -.0165$, 95% CI = [−.0458; .0127]) compared to friend's favorite (mean $\Delta HbO_2 = -.0360$, 95% CI = [−.0652; .0067], z-ratio = 4.24, Tukey-corrected $p < .001$). Pairwise contrasts with experimenter-selected songs (mean $\Delta HbO_2 = -.0443$, 95% CI = [−.0764; −.0121]) did not reach significance (all Tukey-corrected ps > .120). A main effect of ROI was also found ($\chi^2(3) = 7.93$, $p = .047$), showing significantly higher ΔHbO_2 levels in lDLPFC (mean $\Delta HbO_2 = -.0165$, 95% CI = [−.0492; .0166]) compared to rMPFC (mean $\Delta HbO_2 = -.0592$, 95% CI = [−.0910; −.0274], z-ratio = 2.93, Tukey-corrected $p = .018$, Cohen's d = .04), and of rDLPFC (mean $\Delta HbO_2 = -.0009$, 95% CI = [−.0341; .0322], z-ratio = 3.95, Tukey-corrected $p = .001$, Cohen's d = −.06) and lMPFC (mean $\Delta HbO_2 = -.0525$, 95% CI = [−.0844; −.0206], z-ratio = 3.48, Tukey-corrected $p = .003$, Cohen's d = −.05). Three significant two-way interactions among predictors were also observed: 1) The interaction between Song Category and ROI was significant (described in

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[4] Reported values are in μM units.

Fig. 4, A with mean values of ΔHbO_2 projected on a virtual brain; $\chi^2(6) = 29.30$, $p < .001$), indicating that favorite and friend's favorite songs led to higher activation in the DLPFC (see Table 1 for statistics) than experimenter-selected songs. This effect was particularly pronounced in the more lateral (as opposed to medial) part of the lDLPFC. The medial parts of the PFC did not have significant changes in ΔHbO_2 (all ps > .179). 2) The interaction between Song Category and Social Condition was significant ($\chi^2(2) = 19.64$, $p < .001$), indicating greater activity in the whole PFC when listening to favorite songs compared to friend's favorite and experimenter-selected songs, but only during the joint condition (see Table 2). 3) The interaction between Social Condition and ROI ($\chi^2(3) = 14.39$, $p = .002$) was significant, with post-hoc tests revealing only a slight decrease of ΔHbO_2 in the rMPFC in the joint condition (mean = −.0615; 95% CI [−.0996, −.0234]), compared to the solo condition (mean = −.0435; 95% CI [−.0771, −.0100], z-ratio = −2.05, Tukey-corrected $p = .040$; Cohen's d = −.09).

3.2.2. *Pleasure boosted PFC activation in the joint condition, but not in the solo condition*

To elucidate the relationship between pleasure and cortical activation, we additionally measured whether the pleasure reported by participants during and after music listening (i.e., Continuous Pleasure) and after (Overall Pleasure) could predict PFC oxygenation values. Specifically, we tested the model: ΔHbO_2 ~ Social Condition * ROI * **Pleasure** + (1 + Social Condition | Subject) + (1 | Song ID) + (1 | Channel), from Section 3.2.1. replacing the predictor Song Category first with *Continuous* Pleasure, and subsequently with *Overall* Pleasure ratings (indicated with **Pleasure**).

For *Continuous* Pleasure ratings, the model ($\chi^2(1) = .02$, $p = .887$; $R^2_{(m)} = .008$, $R^2_{(c)} = .112$, ICC = .11) revealed a significant interaction between Social Condition and *Continuous* Pleasure ($\chi^2(1) = 7.12$, $p = .008$) confirming that increased activity across the entire PFC was associated to higher levels of pleasure in the joint condition ($\beta_{std} = .0035$, 95% CI [.0023, .0047], z-ratio = 6.58, Tukey-corrected $p < .001$), but not in the solo condition ($\beta_{std} = -.0006$, 95% CI [−.0016, .0005], z-ratio = −1.27, Tukey-corrected $p = .366$). A main effect of *Continuous* Pleasure was also found ($\chi^2(1) = 32.72$, $p < .001$, $\beta_{std} = .0015$, 95% CI = [.0007, .0022]), showing that the higher the pleasure the higher the activation over the entire PFC (see Fig. 4, B). A significant main effect of ROI ($\chi^2(3) = 35.97$, $p < .001$), indicated lower levels of ΔHbO_2 in MPFC ROIs compared to DLPFC (Tukey-corrected ps < .018), with the exception of a non-significant difference between lDLPFC and lMPFC (Tukey-corrected $p = .066$). No significant difference was observed between bilateral DLPFC (Tukey-corrected $p = .757$) or within MPFC (Tukey-corrected $p = .964$). The interaction between ROI and *Continuous* Pleasure was not significant ($\chi^2(3) = 6.09$, $p = .107$). Exploratory examination of individual ROIs suggested positive modulatory effects in the lDLPFC (βstd = .0037, 95% CI [.0021, .0053], z-ratio = 5.84, Tukey-corrected $p < .001$) and rDLPFC (βstd = .0017, 95% CI [−.0001, .0034], z-ratio = 2.45, Tukey-corrected $p = .052$), whereas no such effects were observed in the MPFC (all ps > .898). Finally, the model confirmed the significant interaction between Social Condition and ROI ($\chi^2(3) = 37.34$, $p < .001$), indicating a decrease of ΔHbO_2 on the rMPFC in the joint condition (mean = −.0762; 95% CI [−.1138, −.0385]) compared to the solo condition (mean = −.0421; 95% CI [−.0753, −.0089], z-ratio = −2.07, Tukey-corrected $p = .038$; Cohen's d = −.10).

Table 1 – Post-hoc analysis of the Song Category * ROI significant interaction on ΔHbO_2. Contrasts with respective *p*-values and effect sizes (Cohen's d) are reported. Significant effects are highlighted in bold. Only DLPFC regions are included due to non-significant results in MPFC (all ps > .179). Tukey correction was applied to all contrasts.

Contrast	rDLPFC		lDLPFC	
	p-value	d	*p*-value	d
friend's favorite > experimenter-selected	.194	.08	.276	.07
favorite > friend's favorite	**.002**	**.10**	**.007**	**.08**
favorite > experimenter-selected	**.001**	**.18**	**.003**	**.15**

Table 2 – Post-hoc analysis of the Song Category * Social Condition significant interaction on ΔHbO_2. Contrast with respective *p*-values and effect size (Cohen's d) are reported. Significant effects are highlighted in bold. Tukey correction was applied to all contrasts.

Contrast	whole PFC			
	Joint		Solo	
	p-value	d	*p*-value	d
friend's favorite > experimenter-selected	1.000	.004	.548	.04
favorite > friend's favorite	**< .001**	**.134**	.448	−.02
favorite > experimenter-selected	**.005**	**.138**	.851	.02

For *Overall* Pleasure, the model ($\chi^2(1) = .02$, $p = .884$; $R^2_{(m)} = .008$, $R^2_{(c)} = .111$, ICC = .10) revealed again a significant interaction with Social Condition, here for *Overall* Pleasure ($\chi^2(1) = 6.59$, $p = .010$) indicating that the entire PFC was modulated only in joint ($\beta_{std} = .0027$, 95% CI [.0018, .0036], z-ratio = 6.63, Tukey-corrected $p < .001$), and not in solo (Tukey-corrected $p = .953$). Additionally, the model revealed two main effects consistent with those observed with *Continuous* Pleasure: a main effect of *Overall* Pleasure ratings ($\chi^2(1) = 39.09$, $p < .001$, $\beta_{std} = .0013$, 95% CI = [.0007, .0019]), and of ROI ($\chi^2(3) = 35.95$, $p < .001$). The interaction between *Overall* Pleasure and ROI was significant ($\chi^2(3) = 9.67$, $p = .022$), showing a positive modulatory effect in the lDLPFC ($\beta_{std} = .0033$, 95% CI [.0020, .0045], z-ratio = 6.68, Tukey-corrected $p < .001$) and in rDLPFC ($\beta_{std} = .0018$, 95% CI [.0005, .0031], z-ratio = 3.46, Tukey-corrected $p = .002$), but not in the MPFC regions (all ps > .936). Also, the interaction between Social Condition and ROI was confirmed ($\chi^2(3) = 37.13$, $p < .001$), showing again a decrease of ΔHbO_2 in the rMPFC in the joint condition

Table 3 – Post-hoc analysis of the Social Condition * ROI * *Overall* Pleasure significant interaction on ΔHbO_2. Standard values of β (β_{std}), together with 95% Confidence Interval (CI), z-ratio, and *p*-values are provided, divided by Social Condition. Significant effects are highlighted in bold. Tukey correction was applied to all effects.

ROI	Condition							
	Solo				Joint			
	β_{std}	95% CI	z-ratio	*p*-value	β_{std}	95% CI	z-ratio	*p*-value
rDLPFC	.0014	[.0001; .0027]	2.16	**.031**	.0022	[.0007; .0037]	2.83	**.005**
rMPFC	−.0022	[−.0034; −.0011]	−3.78	**< .001**	.0018	[.0006; .0031]	2.87	**.004**
lMPFC	−.0017	[−.0029; −.0004]	−2.68	**.007**	.0023	[.0009; .0037]	3.31	**.001**
lDLPFC	.0021	[.0009; .0033]	3.33	**.001**	.0044	[.0031; .0058]	6.25	**< .001**

(mean = −.0762; 95% CI [−.1137, −.0387]) compared to the solo condition (mean = −.0421; 95% CI [−.0753, −.0090], z-ratio = −2.08, Tukey-corrected $p = .037$, Cohen's d = −.10). Additionally, a three-way interaction between Social Condition, ROI and *Overall* Pleasure was significant ($\chi^2(3) = 8.61$, $p = .035$). Post-hoc tests (detailed in Table 3) revealed that higher Overall Pleasure ratings were associated with increased activity in both the left and right DLPFC in both solo and joint conditions. However, in the left and right MPFC, activity decreased in the solo condition, but increased in the joint condition.

The same statistical analyses were also performed on ΔHbR (for detailed results, see section 2.2. of the Supplemental Information), revealing that generally higher pleasure was significantly related to decreased ΔHbR level across the entire PFC, especially in the joint condition.

3.2.3. *Interpersonal Neural Synchrony was higher in joint (vs solo) music listening, and positively predicted by Pleasure Similarity only in the joint condition*

Aiming to systematically investigate the relationship between Interpersonal Neural Synchrony (INS) and shared pleasure (measured here by Pleasure Similarity), we applied the following LMM separately to INS computed with ΔHbO_2 or ΔHbR, respectively: $INS_{\Delta HbO2}$ or $INS_{\Delta HbR}$ ~ Social Condition * ROI * Pleasure Similarity + (1 + Social Condition | Dyad) + (1 | Song ID) + (1 | Channel). The model predicting $INS_{\Delta HbO2}$ ($\chi^2(1) = 4830.37$, $p < .001$; $R^2_{(m)} = .008$, $R^2_{(c)} = .114$, ICC = .11) showed a significant main effect of Social Condition ($\chi^2(1) = 6.19$, $p = .013$), revealing higher $INS_{\Delta HbO2}$ across the entire PFC in the joint condition (mean = .300; 95% CI [.293, .307]) than in the solo condition (mean = .294; 95% CI [.287, .302], z-ratio = 1.98, Tukey-corrected $p = .048$, Cohen's d = .09; Fig. 5, A). Crucially, a significant main effect of Pleasure Similarity ($\chi^2(1) = 4.67$, $p = .031$, $\beta_{std} = .0219$, 95% CI [−.0143, .0580]) was found. Most importantly, a significant interaction between Social Condition and Pleasure Similarity (see Fig. 5, B; $\chi^2(1) = 5.06$, $p = .024$) indicated that Pleasure Similarity positively predicted $INS_{\Delta HbO2}$ across the entire PFC in the joint condition ($\beta_{std} = .0603$, 95% CI [.0068, .1139], z-ratio = 2.21, Tukey-corrected $p = .027$), but not in the solo condition ($\beta_{std} = -.0166$, 95% CI [−.0635, .0303], z-ratio = −.69, Tukey-corrected $p = .488$). This highlights that shared pleasure in the presence of a friend, measured through Pleasure Similarity, elicited a shared neural response, reflected in higher INS within the pair. The model revealed also a main effect of ROI ($\chi^2(3) = 11.51$, $p = .009$). Post-hoc tests revealed that $INS_{\Delta HbO2}$ was higher in the rMPFC (mean = .302; 95% CI [.294, .309]) than in the rDLPFC (mean = .293; 95% CI [.285, .300], z-ratio = 2.94, Tukey-corrected $p = .017$; Cohen's d = .15), and the lDLPFC (mean = .293; 95% CI [.286, .301], z-ratio = 2.65, Tukey-corrected $p = .040$; Cohen's d = .14); all other comparisons had ps > .064.

The same analysis on $INS_{\Delta HbR}$ revealed similar results, namely INS was significantly higher in joint condition compared to the solo condition, and more concentrated in the

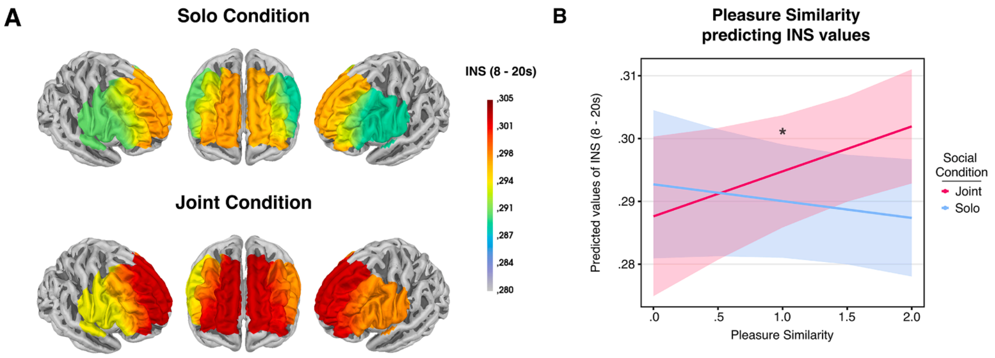

Fig. 5 – Values of INS projected on a virtual brain and predicted by Pleasure Similarity. A) Mean values of INS projected on a virtual brain, showing higher values of INS in the joint condition compared to the solo one; B) The higher the Pleasure Similarity, the higher INS, but *only* in the joint condition. Shaded areas represent 95% confidence intervals. *$p < .05$.

MPFC. Pleasure Similarity showed the same tendency as observed in INS$_{\Delta HbO2}$, both as main effect and in interaction with Social Condition, however less strongly and with marginal significance (for detailed results, see Section 2.2.2. of the Supplemental Information).

4. Discussion

This study aimed to investigate whether listening to music with another person, compared to listening alone, influences subjective musical pleasure while modulating prefrontal activations and interpersonal brain coherence - as measured by INS. We designed an fNIRS hyperscanning experiment where pairs of friends listened to music (both favorite and experimenter-selected) either alone or together and provided pleasure ratings while their PFC oxygenation was monitored in both solo and joint conditions. Results revealed that sharing music listening with another person, as compared to a solo condition, increased the similarity of pleasure ratings and enhanced pleasure-related PFC activity and INS within the pair.

The behavioral data of reported subjective responses revealed that song category significantly influenced both the continuous and overall pleasure ratings, with personal favorite songs eliciting the highest pleasure ratings, followed by the friend's favorite songs, and experimenter-selected songs. However, the continuous pleasure ratings were not affected significantly by the type of social condition (solo/joint) and did not interact significantly with song category. This indicates that while the type of song is a crucial factor in determining pleasure (Blood & Zatorre, 2001), the mere presence of a friend does not substantially alter the immediate pleasure experience. Interestingly however, the overall pleasure ratings provided after listening to the songs showed a significant interaction between song category and social condition, indicating that participants rated their pleasure for their friend's favorite songs slightly higher when listening in a dyadic context compared to alone. Previous studies reported that sharing an emotional experience (such as images or music) with someone else might increase the emotional intensity or enjoyment of this emotional experience (Wagner et al., 2015), while other studies have reported preferences for emotional stimuli experienced in solo conditions (Curzel et al., 2023). The observed inconsistencies might have stem from methodological differences in experimental context (e.g., in the lab or real-life), kind of relationship between participants (e.g., friends or strangers), as well as musical material (e.g., favorite or experimenter-selected music). Our study built on such contrasting outcomes, and our findings now highlight the potential of social sharing to enhance subjective evaluations retrospectively, and specifically for a stimulus explicitly liked by a friend. When listening to a friend's favorite song, participants may feel a greater sense of connection and shared experience (e.g., feeling of togetherness, Bortolini et al., 2024; Chung et al., 2024; Fareri & Delgado, 2014), leading to higher pleasure ratings. Furthermore, social situations and the awareness of another individual's preferences can enhance subjective evaluations through social appraisal mechanisms (Manstead & Fischer, 2001; Parkinson, 2020). This, in turn, can lead an individual to derive additional pleasure from knowing that they are participating in an activity their friend particularly enjoys. Intriguingly and in line with this interpretation, our analysis of Pleasure Similarity, which captures the similarity of pleasure responses within dyads over time, revealed significantly higher values in the joint listening condition than in the solo condition. In our study, participants listened to the same stimuli at the same time as their friend during both conditions. However, and notably as the dyads were unable to see each other's ratings while listening to music, the increased similarity in pleasure ratings does not stem from explicit awareness of the other's exact level of enjoyment but rather from the act of sharing the experience. This suggests that shared experience can synchronize emotional responses to music (Ardizzi et al., 2020; Cross et al., 2024; Hirsch et al., 2023; Mogan, Fischer, & Bulbulia, 2017; Tschacher, Rees, & Ramseyer, 2014), which in turn might enhance social bonding and collective enjoyment (Chabin, Gabriel, Comte, Haffen, et al., 2022; Keller, Novembre, & Hove, 2014; Páez, Rimé, Basabe, Wlodarczyk, & Zumeta, 2015; Stupacher, Maes, Witte, & Wood, 2017). In other words, while sharing music might not generally increase the pleasure, it significantly aligns the affective experience, making it more alike within the pair.

The behavioral observations were extended by fNIRS neural measurements, which revealed that higher pleasure was associated with increased prefrontal activation, in particular in the DLPFC, and even more strongly when music was shared with a friend (joint condition). More specifically, increased activity in DLPFC was associated with both favorite song listening and higher scores of subjective pleasure. This importantly aligns with previous research linking the DLPFC to music reward (Fukuie et al., 2022; Mas-Herrero et al., 2018) and aesthetic judgments (Cattaneo, Lega, Flexas, et al., 2014; Cattaneo, Lega, Gardelli, et al., 2014; Ferrari et al., 2015). Furthermore, these findings indicate that the relationship between social context and musical pleasure can be detected when investigating the underpinning neural correlates, even if it is only partially evident in behavioral outcomes. The lack of significant pleasure-driven activation in MPFC and its significant deactivation during the solo condition further confirms that music-induced pleasure may be significantly reflected in DLPFC activity. This observation is in agreement with animal studies showing that elevated activity in the MPFC leads to a suppression of striatal dopamine-induced activity related to reward responses (Ferenczi et al., 2016). However, the higher activation of the entire PFC specifically in the joint condition might account for a main role played by the MPFC in social contexts (e.g., Ferrari et al., 2015; Krause, Enticott, Zangen, & Fitzgerald, 2012; but see Ishizu & Zeki, 2011, 2013; Vessel, Starr, & Rubin, 2012 for MPFC implications also in aesthetic appreciation). This interpretation is further supported by the INS analyses, showing higher interbrain coherence in MPFC than in DLPFC. This fNIRS study directly shows the functional PFC implications in musical pleasure and social sharing, thus further confirming fNIRS reliability for the study of music cognition and social, affective processes (Curzel, Tillmann, & Ferreri, 2024).

When focusing on inter-brain coherence, wavelet transform assessing the INS within the pairs revealed higher brain synchrony when participants listened to music together (joint condition) than when listening alone (solo condition). This critically suggests that INS is more than an environmental artifact produced by the fact that two persons are exposed to the same stimulus (Holroyd, 2022; Novembre & Iannetti, 2021), but is rather linked to the sharing of it (see also Chabin, Gabriel, Comte, & Pazart, 2022; Koul et al., 2023). It is also worth noting that, in our study, different musical excerpts were used across dyads to manipulate subjective pleasure. Consequently, we did not align continuous pleasure ratings with objective musical events. Rather, we investigated whether INS could be driven by shared affective experience even when the musical material itself varied across dyads. Our approach thus complements and extends previous work on moment-to-moment correspondence between musical structure and neural synchrony (e.g., Hasson, Nir, Levy, Fuhrmann, & Malach, 2004; Trost, Frühholz, Cochrane, Cojan, & Vuilleumier, 2015) and our findings suggest that interpersonal neural alignment can arise from social sharing, beyond stimulus-driven synchronization alone. Specifically for the shared (joint) condition, higher similarity in pleasure ratings predicted the INS: the higher the similarity of pleasure responses within the pair, the higher their INS. Beyond underscoring the importance of social context in modulating neural synchrony (see Nam, Choo, Huang, and Park (2020) for a review), these findings provide evidence for the link between INS and shared affective states (Chabin, Gabriel, Comte, & Pazart, 2022; L. J. Chang et al., 2021), extending recent evidence that co-audition promotes both neural and social alignment within group (Ding, Sun, Tang, & Zhang, 2025). Previous research has shown that synchronized behavior is related to enhanced INS, which in turns promotes cooperation and prosocial behaviors (e.g., Hu, Hu, Li, Pan, & Cheng, 2017; Reinero, Dikker, & Van Bavel, 2021). Music activities can lead to enhanced social bonding (Savage et al., 2021) through different processes, including reward (Curzel, Osiurak, et al., 2024). Therefore, it might be that the ability of music to promote interpersonal emotional tuning (Ardizzi et al., 2020; Czepiel et al., 2021; Páez et al., 2015), here reflected in higher pleasure similarity, might be particularly efficient in promoting neural synchronization between individuals and in fostering their connection. Further research would be needed to assess whether this increased INS might, through musical pleasure, enhance social connection and prosocial behaviors within the dyads sharing music listening.

Altogether, our findings show that social sharing, implemented here as joint *vs* solo listening, modulate the associated neural response and shape how listeners align in their pleasure experiences and engage shared neural processes. These results highlight the intricate interplay between social dynamics, music, and affective processes. The main findings suggest that adopting a social perspective could be an ideal approach for investigating music reward, opening avenues for further exploration of the complexities of human musical experiences in natural settings (Tervaniemi, 2023). Beyond the experimental context, these findings inform broader accounts of music as a driver of social bonding and socio-cognitive processes. In line with the SAME (Shared Affective Motion Experience) model (Overy & Molnar-Szakacs, 2009), shared music listening may promote interpersonal alignment through embodied and temporally synchronized musical experience, with potential implications for socio-cognitive abilities such as theory of mind (Premack & Woodruff, 1978) and for learning contexts.

The results also provide perspectives for therapeutic applications of music. Consistent with the intersubjective music therapy framework grounded in the concept of affective attunement (Raglio, Traficante, & Oasi, 2011; Stern, 1985), our findings show that shared music listening can foster alignment in affective experience and neural activity, modulated by experienced pleasure and participants' music selection. The behavioral (Pleasure Similarity) and neural (INS) indices introduced here may thus offer useful tools for studying affective attunement in music-based interventions.

Overall, our present study highlights music's capacity to generate interpersonal affective and neural alignment, contributing to our understanding of how shared musical experiences can support social interaction, learning, and therapeutic exchange, while offering a methodological framework for their empirical investigation.

CRediT authorship contribution statement

Federico Curzel: Writing – review & editing, Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Barbara Tillmann:** Writing – review & editing, Supervision, Methodology. **Arnaud Fournel:** Writing – review & editing, Resources, Formal analysis, Data curation. **Giacomo Novembre:** Writing – review & editing, Methodology, Conceptualization. **Laura Ferreri:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Conceptualization.

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Declaration of competing interest

The authors declare no competing interests.

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Scientific transparency statement

DATA: All raw and processed data supporting this research are publicly available: https://osf.io/xyznc/?view_only=5e44017cb0714ed28b6a5159e74291ff.

CODE: All analysis code supporting this research is publicly available: https://osf.io/xyznc/?view_only=5e44017cb0714ed28b6a5159e74291ff.

MATERIALS: All study materials supporting this research are publicly available: https://osf.io/xyznc/?view_only=5e44017cb0714ed28b6a5159e74291ff.

DESIGN: This article reports, for all studies, how the author(s) determined all sample sizes, all data exclusions, all data inclusion and exclusion criteria, and whether inclusion and exclusion criteria were established prior to data analysis.

PRE-REGISTRATION: No part of the study procedures was pre-registered in a time-stamped, institutional registry prior to the research being conducted. No part of the analysis plans was pre-registered in a time-stamped, institutional registry prior to the research being conducted.

For full details, see the *Scientific Transparency Report* in the supplementary data to the online version of this article.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cortex.2026.02.012.

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