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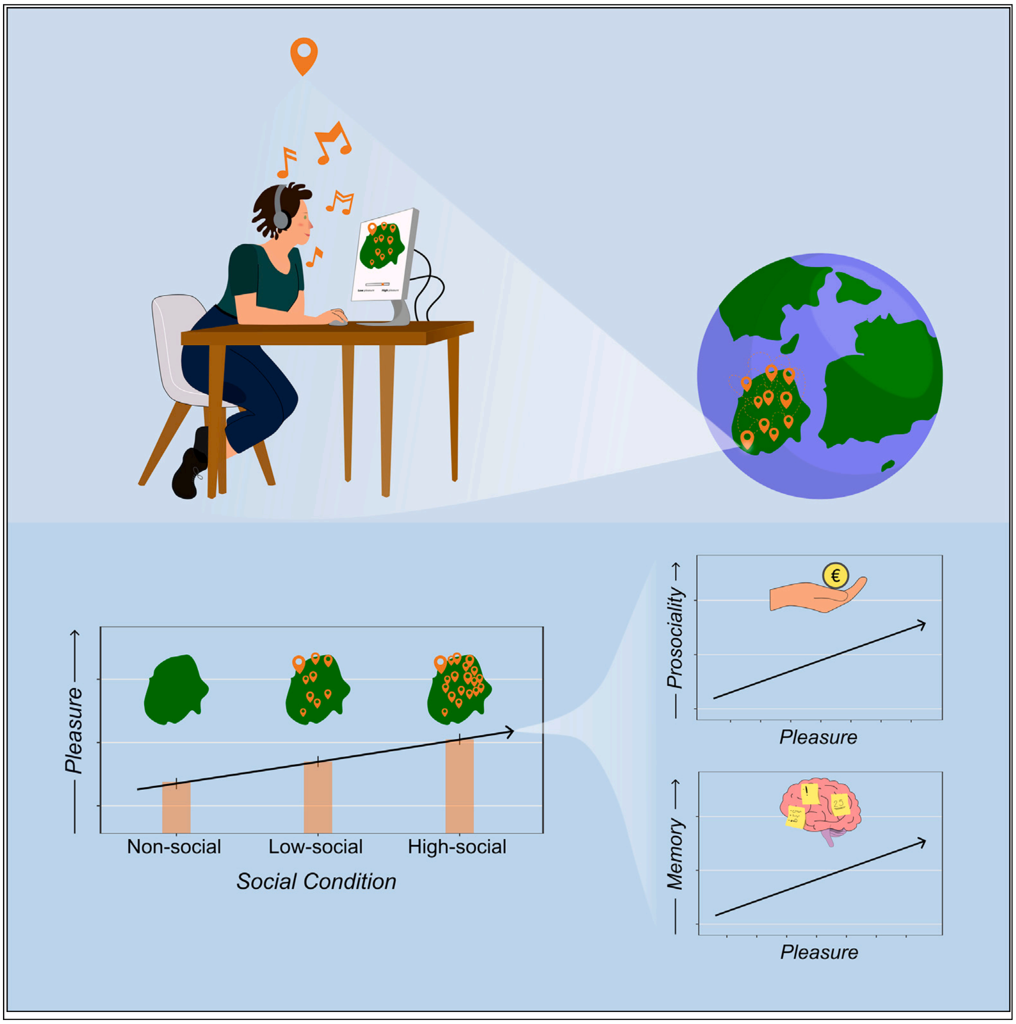

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Highlights

A new ecological experimental paradigm able to modulate music reward is presented

Sharing music listening online enhances pleasure responses

Pleasure is modulated by group size: the more the people, the greater the pleasure

Increased pleasure positively influences prosocial behavior and memory outcomes

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Enhancing musical pleasure through shared musical experience

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SUMMARY

Music and social interactions represent two of the most important sources of pleasure in our lives, both engaging the mesolimbic dopaminergic system. However, there is limited understanding regarding whether and how sharing a musical activity in a social context influences and modifies individuals' rewarding experiences. Here, we aimed at (1) modulating the pleasure derived from music under different social scenarios and (2) further investigating its impact on reward-related prosocial behavior and memory. Across three online experiments, we simulated a socially shared music listening and found that participants' music reward was significantly modulated by the social context, with higher reported pleasure for greater levels of social sharing. Furthermore, the increased pleasure reported by the participants positively influenced prosocial behavior and memory outcomes, highlighting the facilitating role of socially boosted reward. These findings provide evidence about the rewarding nature of socially driven music experiences, with important potential implications in educational and clinical settings.

INTRODUCTION

Music is one of the most pleasant stimuli for humans. Intense feelings of pleasure during music listening have been extensively associated with behavioral measurements (i.e., subjective hedonic and motivational ratings[1–3]), psychophysiological measurements (e.g., heart rate and skin conductance[1,4]), and neural responses in the dopaminergic mesolimbic system (e.g., caudate and nucleus accumbens – NAcc, see[5] for a review). Musical pleasure goes beyond being just a positive feeling per se and can impact and regulate human behavior in terms of both social *and* cognitive outcomes.

The activation of the reward system is causally linked to cooperative, prosocial behaviors, as shown previously by research using secondary rewards (e.g., money[6]) or by the invasive manipulation of reward neural circuits in rodents.[7] Musical experience is intrinsically social,[8,9] and music-related dopaminergic reward system activation can have affiliative emotional and rewarding effects likely to strengthen social bonds in multiple types and sizes of groups.[8] For example, chill-inducing music, as compared to disliked music and silence conditions, promote altruistic behaviors in a dictator socio-economic game.[10]

Rewarding stimuli inducing pleasure responses enhance the storing of new information into long-term memory via the activation of the dopaminergic midbrain and hippocampus.[11–14] Increased musical pleasure is related to better memory and learning outcomes for the music itself[15–18] and for associated verbal materials.[19]

Aiming to modulate the music-pleasurable experience provides promising perspectives with implications for boosting both prosocial behavior and cognitive performance. Previous research has shown that musical pleasure can be bidirectionally (i.e., positively and negatively) modulated in the laboratory. By exciting and inhibiting fronto-striatal pathways via transcranial magnetic stimulation, Mas-Herrero et al.[20] were able to up- and downregulate, respectively, both the perceived pleasure and the monetary value assigned to music[20] (see also[5]). Adopting also a causal approach with pharmacological intervention, Ferreri et al.[21] reported that participants' musical pleasure and the motivation for music listening can be increased or decreased, respectively, by pharmacologically blocking or enhancing dopaminergic transmission. The decreased pleasurable experience caused by the blocked dopaminergic transmission led also to the disruption of the positive effect of musical pleasure on memory outcomes (see also[14,16,22]). However, aiming to get closer to every-day musical

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experience,[23] the question arises whether musical pleasurable experiences can be modulated (and more specifically increased) by non-invasive and more ecological means.

Motivating perspective come from social and affective neuroscience research. Stimuli that evoke emotional episodes (i.e., pictures) are rendered more pleasant when shared with somebody, and this social sharing is associated to the activation of the reward dopaminergic brain circuitry.[24] Musical activities in a group or ensemble promote interpersonal coordination,[25] social-empathic behavior,[26,27] positive emotional sharing,[28] and lead also to increased prefrontal inter-brain synchronization among individuals.[29] Individuals with stronger reward sensitivity to music tend to have larger and more connected pathways between the sensory cortices' areas and emotion and social processing areas (e.g., insula and medial prefrontal cortex[30,31]). In this vein and crucially, Liljeström et al.[32] showed, in a laboratory setting, that listening to self- or experimenter-selected music together with a close friend or partner aroused more intense emotions than listening alone. To the best of our knowledge, only a few studies investigated the sharing of music listening in group (instead of dyads of participants). Sutherland et al.[33] (see also Egermann et al. on the same experiment[34]), compared a group listening condition to a solitary one, revealing no significant difference in the occurrence of chills. In a similar vein, a recent study found that group listening even led to decreased pleasure responses compared to a solitary condition.[35] However, these results were attributed to the impossibility to replicate typical, real-life social mechanisms in controlled experimental settings. Thus, more research is needed to isolate and understand the mechanisms underlying reward modulations in shared music listening contexts, as well as potential benefits of these modulations on socio-cognitive abilities, such as memory and prosociality.

To these aims, we ran a set of three online experiments across two countries (Experiment 1 in USA, Experiments 2 & 3 in France) and recorded pleasure responses while participants were sharing (or not) music listening with others. To avoid potential confounding factors coming from the physical presence of another person (see e.g.,[36]) and the closeness to the other participants (see e.g.,[32]), we developed an online paradigm in which we simulated the presence of other participants (i.e., strangers) connected (or not) at the same time as the participant and shown as different pins appearing on a geographical map (Figure 1). In all experiments, we asked participants to listen to music (pop rock in Experiment 1, different genres in Experiment 2, classical music in Experiment 3) under different sharing conditions (i.e., from no sharing to high social sharing) and to provide pleasure and other control subjective ratings (i.e., beauty, interest, valence, and familiarity), also taking into account individual differences in music reward sensitivity (i.e., musical hedonia, as measured with the Barcelona Music Reward Questionnaire, BMRQ[37]). To extend the investigation of socially-modulated pleasure, we further measured participants' prosocial behaviors (Experiment 2) and memory performance after music listening (Experiment 3) with adapted socio-economic games[38,39] and recognition-recollection task,[40] respectively. We made the hypothesis that the (illusory) social sharing of music listening experience would result in increased pleasure responses as compared to a solo, non-social listening experience, in turn promoting pleasure-driven improvements of cognitive (i.e., memory) and prosocial behavior outcomes.

We consistently found that the illusion of sharing music listening online with strangers significantly increased the musical pleasure reported by participants. Critically, we found that the increased musical pleasure had beneficial effects on both prosocial and memory outcome measures, thus supporting the interpretation in terms of the activation of the reward system via the social sharing of music listening and confirming its critical role for human cognition and behavior.

RESULTS

Experiment 1

We first aimed at investigating whether the sharing of music listening might increase pleasure ratings provided for the music listening. Participants from USA (*N* = 52; 33 women, mean age: 34.72 ± 10.78 years) were asked to listen to their favorite or experimenter-selected musical excerpts of their preferred genre (i.e., pop-rock) while being connected to an online platform with other participants (i.e., having the illusion of sharing music in small groups of 3–5 persons or bigger groups of 18–20 persons; Low- and High-Social Conditions, respectively) or alone (i.e., Non-Social condition, within-subjects design, Figure 1). We therefore investigated whether the pleasure reported after each song was higher in the shared music listening situation than the solo listening situation, also controlling for participants' musical hedonia (measured with the Barcelona Music Reward Questionnaire, BMRQ[37]), gender and the song category through linear mix models (LMM) with forward selection approach (see STAR methods section). The best model (Pleasure ∼ Social Condition + Song Category + Gender + (1|Subject); $\chi^2(1) = 539$, $p < 0.001$; $R^2_{(m)} = 0.347$, $R^2_{(c)} = 0.433$, ICC = 0.132; see Table S1) showed that the Social Condition ($\chi^2(2) = 6.47$, $p = 0.039$) significantly predicted Pleasure responses (see Figure 2): the larger the group sharing during music listening, the higher the pleasure ratings reported by participants. Post-hoc tests showed that the Pleasure during the High-Social condition (mean = 68.32; 95% CI [64.84, 71.80]) was significantly higher than during the Non-Social (solo) one (mean = 63.88; 95% CI [60.41, 67.35], t(675) = 2.536, $p = 0.031$, Tukey-corrected; Cohen's d = 0.232). No other contrasts between the other social conditions were statistically significant (Non-Social vs. Low-Social and Low-Social vs. High-Social, all ps > 0.323). A main effect of Song Category ($\chi^2(1) = 400$, $p < 0.001$) indicated that higher pleasure ratings were provided for favorite (vs. experimenter selected) songs. Gender also showed a significant effect ($\chi^2(1) = 9.17$, $p = 0.002$), with higher pleasure scores reported by males than females. Each fixed factor had a GVIF of 1, attesting that there were no multicollinearity issues.

The same model was used to predict the other subjective ratings. As for the Pleasure responses, Beauty was significantly predicted ($\chi^2(1) = 755$, $p < 0.001$; $R^2_{(m)} = 0.267$, $R^2_{(c)} = 0.387$, ICC = 0.164) by both Social Condition ($\chi^2(2) = 11.5$, $p = 0.003$) and Song Category ($\chi^2(1) = 282$, $p < 0.001$), with higher Beauty scores reported in the High-Social (mean = 71.05; 95% CI [67.66, 74.43]) compared to the Non-Social conditions (mean = 65.66; 95% CI [62.28, 69.05], t(675) = 3.379, $p = 0.002$, Tukey-corrected; Cohen's d = 0.309). For the other subjective measures, there was no effect of Social Condition (all ps > 0.204), but favorite songs led to significantly higher Valence ($\chi^2(1) = 41.0$, $p < 0.001$), Interest ($x^2(1) = 290$, $p < 0.001$), and Familiarity ($\chi^2(1) = 499$, $p < 0.001$) ratings than did experimenter-selected songs.

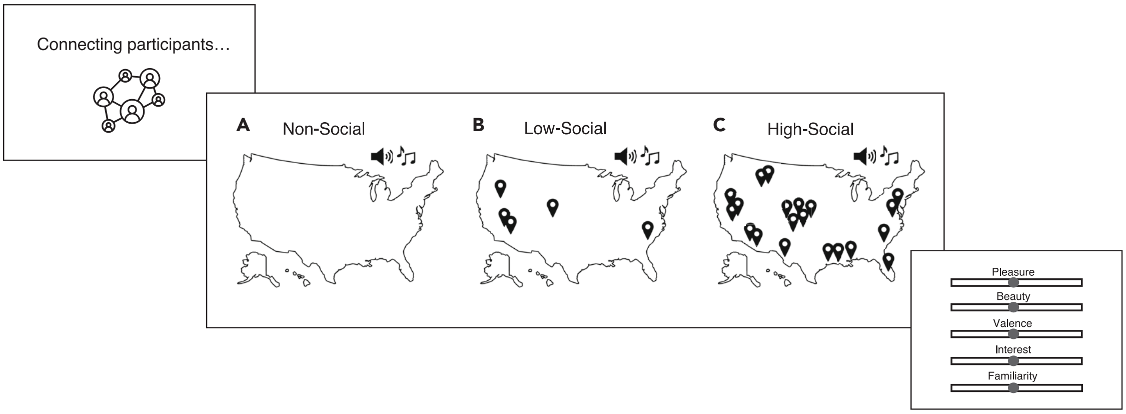

Figure 1. Schematic representation of the music task of Experiment 1

At the beginning of each trial, a video simulating the synchronization of the experiment with other participants was shown. Successively, (illusory) connected participants appeared as pins on a map of the country. Each participant listened to a total of 18 different musical excerpts (i.e., self- and experimenter-selected songs) under three social conditions: (A) Non-Social (0 pins), (B) Low-Social (with 3, 4, or 5 pins), (C) High-Social (with 18, 19, or 20 pins). After each excerpt, the map disappeared, and participants were asked to provide pleasure and other control subjective measures through a 0–100 scale slider. In Experiments 2 and 3, the same implementation was adapted with maps of France for Experiments 2 and 3.

Overall, the results of Experiment 1 showed that participants' Pleasure and Beauty responses were significantly predicted by the Social Condition, and importantly, were significantly increased during the High-Social condition compared to the Non-Social condition. We did not find any other significant effect of Social Condition on the other subjective measures. Furthermore, Song Category significantly impacted each measure, showing that participants perceived their favorite songs as more pleasant than the unfamiliar, experimenter-selected songs.

Experiment 2

Experiment 1 revealed that the mere illusion of sharing music listening with others increases the pleasure felt by participants. Experiment 2 aimed to extend the findings of Experiment 1 by implementing a different design (between-rather than within-subjects), in a different country (France rather than USA), employing different musical styles and additionally investigating the potential impact of socially-driven pleasure on prosocial behaviors. French participants ($N = 111$; 62 women, 1 non-binary, mean age: 29.62 ± 6.67 years) performed the same task as in Experiment 1 and additionally provided continuous pleasure ratings while listening to their favorite and experimenter-selected music in solo or group simulations (Non-, Low-, High- Social Conditions; between-subjects design). In order to extend previous results, the experimenter-selected music included songs from their non-preferred genres (see STAR methods section).

Following the same analysis approach as for Experiment 1, the best model (Pleasure ∼ Social Condition + Song Category + (1|Subject); $\chi^2(1) = 2177$, $p < 0.001$; $R^2_{(m)} = 0.472$, $R^2_{(c)} = 0.518$, ICC = 0.086; see Table S2) confirmed a significant main effect of Song Category ($\chi^2(1) = 989$, $p < 0.001$), with higher pleasure ratings for favorite experimenter-selected music, and a significant main effect of Social Condition ($\chi^2(2) = 6.14$, $p = 0.046$). High-Social conditions (mean = 75.78; 95% CI [73.42, 78.14]) showed significantly higher pleasure ratings when compared to Non-Social condition (mean = 71.80; 95% CI [69.53, 74.07], t(108) = 2.406, $p = 0.047$, Tukey-corrected; Cohen's d = 0.257; Figure 2). No other contrasts between the other Social Conditions were statistically significant (Non-Social vs. Low-Social and Low-Social vs. High-Social, all ps > 0.20). Each fixed factor had a GVIF of 1, attesting that there were no multicollinearity issues, and the same was observed for all the following models. Similarly, the model predicting Continuous Pleasure ratings (Continuous Pleasure ∼ Social Condition + Song Category + (1|Subject); $\chi^2(1) = 4936$, $p < 0.001$; $R^2_{(m)} = 0.502$, $R^2_{(c)} = 0.557$, ICC = 0.111) revealed a significant main effect of Song Category ($\chi^2(1) = 989$, $p < 0.001$) and a significant main effect of Social Condition ($\chi^2(2) = 7.95$, $p = 0.019$), with the High-Social condition (mean = 66.83; 95% CI = [65.33, 68.32]) showing significantly higher Continuous Pleasure ratings than the Non-Social condition (mean = 64.07; 95% CI [62.64, 65.51], t(108) = 2.637; $p = 0.026$, Tukey-corrected; Cohen's d = 0.301). No other contrasts between the other Social Conditions were statistically significant (all ps > 0.079). Control affective ratings of Beauty ($\chi^2(1) = 507$, $p < 0.001$), Interest ($\chi^2(1) = 685$, $p < 0.001$) and Familiarity ($\chi^2(1) = 2299$, $p < 0.001$), but not Valence ($p > 0.05$) were higher for favorite rather than experimenter-selected songs. No effect of Social Condition on control affective ratings was found (all ps > 0.113).

Crucially, Experiment 2 also investigated whether the socially-driven modulation of pleasure could influence social behavior. To this aim, we tested whether the pleasure felt under different social conditions modulated participants' prosociality measured after music listening through adapted versions of the Ultimatum (i.e., money willing to offer to a virtual partner[39]) and Dictator games (i.e., money willing to offer to a non-profit institution or time willing to devote to a further part of the experiment[38]). The selected best model assessing the Ultimatum scores with pleasure ratings (Ultimatum offers ∼ Social Condition + Pleasure + (1|Subject); $\chi^2(1) = 3.94$, $p = 0.047$; $R^2_{(m)} = 0.041$; $R^2_{(c)} = 0.380$, ICC = 0.353; see Table S3) revealed a main effect of Pleasure on Ultimatum's games offers: the higher the pleasure ratings provided after having listened to the music, the higher the monetary offers participants were willing to share with a virtual partner ($\chi^2(1) = 7.75$,

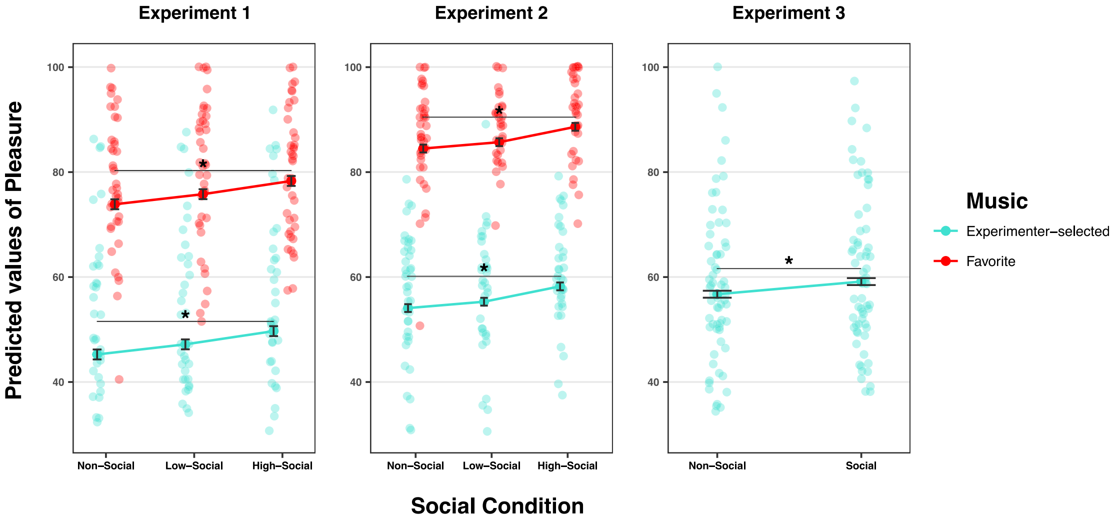

Figure 2. Predicted values of pleasure ratings as a function of the different social sharing conditions in the 3 Experiments

All experiments showed the main effect of Social Condition, indicating that the higher the (illusory) social sharing, the higher the pleasure reported by participants. Dots represent predicted values collapsed by the random factor (subject); mean values with standard error bars are reported for each Social Condition and Song Category. * = $p < 0.05$

$p = 0.005$; $\beta_{std} = 0.18$, 95% CI [0.05, 0.30]; Figure 4A). No effect of Social Condition was found on the Ultimatum's games offers ($\chi^2(2) = 2.04$, $p = 0.361$). The same model computed assess the Ultimatum scores, but now with Continuous Pleasure ratings means as predictor (Ultimatum offers ~ Social Condition + Continuous Pleasure + (1|Subject); $\chi^2(1) = 1.88$, $p = 0.170$; $R^2_{(m)} = 0.027$; $R^2_{(c)} = 0.380$, ICC = 0.363) confirmed a significant effect of Pleasure ($\chi^2(1) = 3.96$, $p = 0.047$; $\beta_{std} = 0.13$, 95% CI [0.002, 0.25]), with no effect of Social Condition ($\chi^2(2) = 1.90$, $p = 0.387$). Social Condition and Pleasure ratings (both overall and continuous) did not reveal an effect on the Dictator games outcomes, thus showing no direct influence of pleasure or social sharing on the amount of a possible donation nor on participants' time availability (all ps > 0.067 resulting from linear regressions; see Tables S9 and S10 for frequency distribution of the outcomes).

In sum, results from Experiment 2 confirmed the positive effect of the social sharing of music on the reported pleasure on a different sample of participants, from a different country, and with different types of music (i.e., even when non-preferred). Experiment 2 further revealed that the higher the pleasure felt during the music listening, the higher the prosocial outcomes resulting from an Ultimatum (but not Dictator) game task.

Experiment 3

Experiment 3 aimed to confirm the previous findings, extend them to unfamiliar music and further investigate the potential impact of socially-driven pleasure on memory performance. We first tested whether listening to unfamiliar, classical music under two Social Conditions (i.e., Non- and Low-Social; within-subjects design) could modulate the pleasure reported by participants ($N = 67$; 56 women, mean age: 23.52 ± 4.44 years).

Following the same analysis approach as for Experiments 1 and 2, we found that the resulting best model (Pleasure ~ Social Condition + (1| Subject); $\chi^2(1) = 1043$, $p < 0.001$; $R^2_{(m)} = 0.003$, $R^2_{(c)} = 0.415$, ICC = 0.413; see Table S4) confirmed a significant main effect of Social Condition ($\chi^2(1) = 5.47$, $p = 0.019$), with higher pleasure scores reported during the social sharing condition (mean = 60.05; 95% CI [56.35, 63.75]) than during the solo, Non-Social condition (mean = 57.64; 95% CI [53.93, 61.35]; $t(984) = 2.338$, $p = 0.020$, Tukey-corrected; Cohen's d = 0.145; Figure 2). Each fixed factor had a GVIF of 1, attesting that there were no multicollinearity issues, and this was observed for all the computed models. No main effects were found for the others affective control measures (all ps > 0.245).

Based on the same analysis approach employed for social outcomes in Experiment 2, we explored whether the pleasure felt during music listening could influence the recognition of music itself through an old/new recognition paradigm after an interference phase following the music listening task (Figure 3).

We therefore tested whether the social condition and the pleasure felt by participants could predict the correctly recognized (or not) items through a logistic regression LMM (Recognition ~ Social Condition + Pleasure + (1|Subject); $\chi^2(1) = 3.77$, $p = 0.052$; $R^2_{(m)} = 0.007$, $R^2_{(c)} = 0.052$, ICC = 0.045). Results revealed a main effect of Pleasure: the higher the pleasure ratings reported by participants after each excerpt, the better the Recognition performance for the previously listened excerpts ($\chi^2(1) = 3.99$, OR = 1.16, $p = 0.046$; Figure 4B). The same model did not reveal an effect of Pleasure on Recollection (i.e., when predicting whether the correctly recognized excerpts were also recollected or not; Remember/Know/Guess paradigm[40]), nor on Source Memory (i.e., when predicting whether correctly recognized excerpts' listening social context was also recollected or not; Figure 3; all ps > 0.566). No main effects of Social Condition were found on memory outcomes (all ps > 0.075).

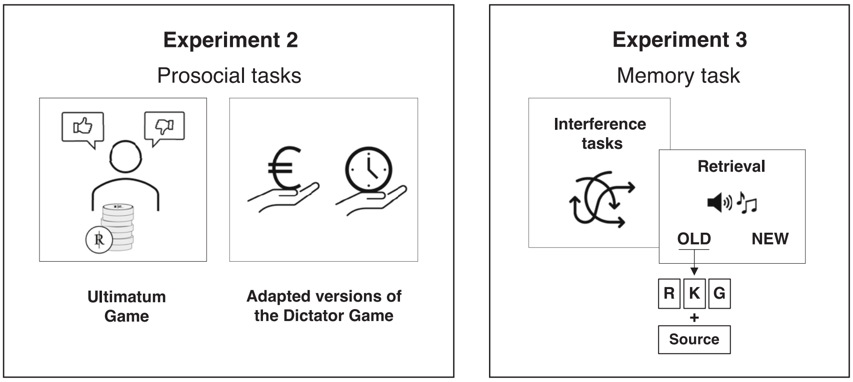

Figure 3. Prosocial and memory tasks

In Experiment 2 participants had to complete three prosocial tasks. The first was an Ultimatum Game, in which each participant was coupled with a partner and had to propose an offer picking from a 100 coins budget assigned in each trial on a total of 10 trials. The *illusory* partner could accept the offer, leading both to win the amount or not, thus leading both to lose the amount. The second and third prosocial tasks were adapted versions of the Dictator Game, where participants were asked if they would donate an amount (5 options: €10, €20, €30, €40, €50) to an association in the eventuality of winning the final lottery (i.e., a €50 voucher) and whether they would be available to help us and continue with another phase of the study (4 options: 0, 5, 10, 20 min). In Experiment 3, after an interference phase (a Flanker task and a reaction time task), participants had to complete a music memory task testing their recognition (old/new paradigm), recollection (remember/know/guess paradigm) and source memory (i.e., retrieving the social context of the encoding).

Meta-analysis of individual participant data

We further conducted a meta-analysis of Individual Participant Data (IPD[41]) to evaluate the robustness of the effect of social condition on pleasure ratings by merging data from the three experiments (Pleasure ~ Social Condition + Song Category + (1|Subject); $\chi^2(1) = 334.3$, $p < 0.001$; $R^2_{(m)} = 0.320$, $R^2_{(c)} = 0.511$, ICC = 0.281; see Table S5).

Results indicated a significant overall effect of the Social Condition on the Pleasure felt by participants ($\chi^2(1) = 12.1$, $p < 0.001$), who reported increased pleasure ratings when sharing music with others (mean = 71.84; 95% CI [59.42, 84.27]) as compared to the solo, Non-Social condition (mean = 69.13; 95% CI [56.94, 81.32]; t(2608) = 3.479, p = < 0.001, Tukey-corrected; Cohen's d = 0.159). Similarly to the results of the analyses of each experiment, the expected effect of Song Category ($\chi^2(1) = 1221$, $p < 0.001$) was also significant, confirming higher pleasure for favorite songs (mean = 85.26; 95% CI [73.22, 97.31]) than experimenter-selected songs (mean = 55.71; 95% CI [43.22, 68.20]; t(2395) = 34.776, p = < 0.001, Tukey-corrected; Cohen's d = 1.74). Each fixed factor had a GVIF of 1, attesting that there were no multicollinearity issues. The intraclass correlation (ICC) for Subject was 0.222, indicating that 22.2% of the total variance in pleasure ratings was due to differences between participants. The ICC value for Experiment was 0.059, indicating that 5.9% of the total variance in pleasure ratings was due to differences between experiments. All in all, these findings provide a robust support for the increase of pleasurable reward responses through the (illusory) sharing of music listening.

DISCUSSION

Music is an intrinsically social and pleasant stimulus activating the dopaminergic reward system.[42] In this study, we investigated whether the manipulation of the social sharing of music could impact the pleasure it generates, and further modulate reward-related prosocial[7] and memory outcomes.[22] To this aim, we implemented a behavioral online protocol simulating a social shared experience during music listening.

The main finding of our study is that listening to music with others online can significantly increase the pleasure experience: the higher the musical sharing with others, the higher the pleasure reported by participants. Crucially, we explored and replicated this effect: (i) across three different experiments; (ii) under different experimental conditions that employed different kinds of music stimuli (participants' favorite pop-rock music, mix of experimenter-selected musical genres, classical music); (iii) across two countries (USA and France); (iv) under different social manipulations (small and large "sharing" groups); and (v) via different experimental designs (within- and between-subjects). A positive modulation of social sharing on beauty was also found in Experiment 1, thus indicating that reward-related aesthetic appraisal judgments[43] can be influenced by sharing an experience with others. However, this result was not observed in Experiments 2 and 3, and no effect of social condition was found for other affective control measures (interest, valence, familiarity). This result pattern suggests that the social sharing of the musical experience specifically acts on pleasurable responses, whether this is measured continuously (as in Experiment 2) or using overall ratings (as in Experiments 1, 2 and 3), and as further confirmed by the IPD meta-analysis.

Due to their intrinsically social nature, human beings tend to prefer to experience the environment – in particular when it is emotional – with peers rather than alone,[44] thus showing the need and motivation of sharing emotions socially.[45] Our findings are in line with previous studies showing the effect of social sharing on evoked emotions. For example, sharing an emotional experience (e.g., looking at emotional images[24,46]) with a peer increases its emotional intensity. In the same vein, using online paradigms, Shteynberg et al.[47] reported that the illusion of sharing valenced images was sufficient to intensify emotional reactions. This effect was associated with the activation of the reward system,

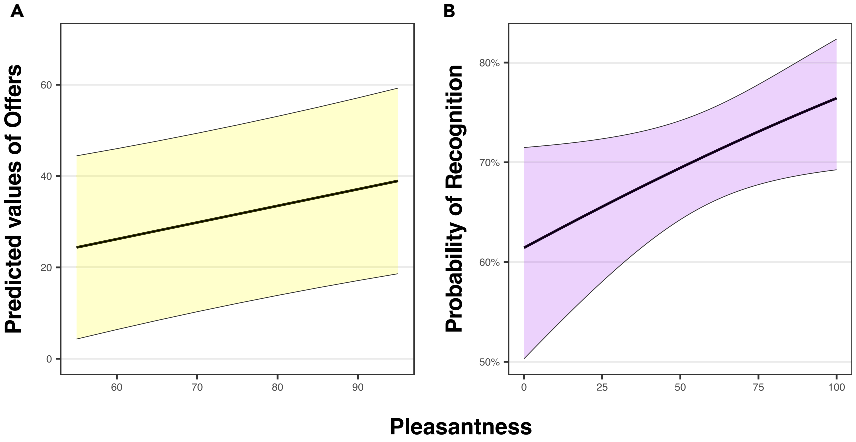

Figure 4. Prosocial and memory recognition results

Predicted probability of Ultimatum Game's offers (Experiment 2) (A) and memory performance (music excerpts recognition, Experiment 3) (B) as a function of pleasantness subjective ratings. Shaded areas represent 95% confidence intervals.

supporting the hypothesis that social sharing of emotions is *per se* hedonically rewarding.[24] Research in music cognition reported, however, contrasting results about the role of music sharing in emotion regulation. While people usually experience more intense emotion and report more music-related enjoyment when listening to music with a close friend or partner rather than alone,[32,48] several studies comparing group versus solo music listening in the laboratory failed to replicate the effect of social sharing on pleasure[33–35] and related psychophysiological measures (e.g., skin conductance[34]). This might be due, at least in part, to the difficulty of replicating in the laboratory an ecologically valid social music listening situation that is able to promote pivotal social mechanisms, such as emotional contagion,[49] social appraisal,[50] oriental calibration,[51] in-group connectedness,[35] and closeness of the relationships.[32,52] Furthermore, the level of concentration and absorption might impact the affective response to music. Indeed, although social contact and the sharing of music-related activities constitute main facets of music reward,[37] music pleasurable responses also depend on intimate, private events able to alter self-consciousness states.[53,54] In our online paradigm, participants had only the *illusion* of sharing music with others, via an online ecological scenario, mirroring individuals' tendency to share musical content in digital platforms. This allowed preserving both an intimate experience that favored focusing on the music, while promoting the sense of sharing the state of simultaneous co-attention with one's group members (by seeing the appearance of the pins on the map). As proposed by Shteynberg et al.,[47] any variable that could increase the extent to which the self and the other can be fused in a single agent (i.e., the perception of being part of the same group), could intensify emotions. Accordingly, our results show that the increased social sharing of an emotional stimulus (here music) also increased the pleasure reported by the participants. Taken together, these findings suggest that our paradigm constitutes an ideal condition for boosting musical pleasure. In addition, this paradigm allowed us to show that such socially increased pleasure responses increased prosocial and memory outcomes.

Prosocial behaviors can be intrinsically rewarding thanks to the interaction with others.[55] Furthermore, positive feelings, such as happiness, have been shown to reinforce and predict prosocial behavior.[56] In music research, a link emerges between reward-related aspects and prosocial behaviors. Fukui and Toyoshima[10] showed that pleasure responses associated with chill-inducing, but not with disliked music, were able to increase prosocial behaviors in a dictator game task. At the neural level, this could be driven by modulations in key nodes of the mesolimbic reward system, regulated by neuromodulators such as dopamine, oxytocin and serotonin.[7,57] In Experiment 2, we observed that stronger pleasure led to an increased total amount of money offered to an (illusory) partner in the Ultimatum's game, with a predicted response projected into a fair/equitable range (40:60 or 50:50, as considered by Luo et al.[58] and by Wu et al.[59]). Based on previous findings, it is therefore likely that dopaminergic transmission underpinning musical pleasure increased by the social sharing of music listening could have in turn promoted prosocial behaviors. The other prosocial measures employed in this study (i.e., the adapted versions of the Dictator Game) were not significantly modulated by the pleasure and the social condition, probably because these were not oriented toward a group member (as it was the case for the Ultimatum Game; see also[10]). It is also noteworthy that participants were in general willing to offer their time availability in all the social conditions, including the Non-Social one (see Table S9). This could be explained by the fact that the experiment was conducted on a voluntary basis, so the participants were already prompted to help an organization (i.e., research team). For these reasons, the Ultimatum Game offers represented the more reliable and sensitive measure for describing a cooperative/prosocial tendency after the musical listening manipulation.[60]

In addition to social behavior, the influence of shared listening experiences extends to cognition. Experiment 3 showed the effect of increased pleasure responses on memory. Stronger pleasure responses were associated with better memory performance: the higher the level of reported pleasure, the better the recognition of unfamiliar musical excerpts after an interference phase. The link between reward responses and memory has been previously reported, notably in findings showing that rewarding stimuli, such as money,[61] curiosity-states,[62] intrinsic learning,[13,14] and even music[17,19,22] can promote long-term memory. This has been shown to be neurally associated to the dopaminergic regulation of the mesolimbic reward-hippocampal loop,[11,13,16] supporting the hypothesis that responses boosted by social sharing might promote memory formation and consolidation processes.

Our study showed that the sharing of music listening could increase the pleasure felt by participants. In addition, musical pleasure promoted both prosocial behavior and memory outcomes, confirming the role of reward responses in human behavior and cognition (see e.g.,[63]). Together with previous findings, our results suggest that the manipulation of social sharing of music listening specifically modulated dopaminergic-dependent reward processes (i.e., increased prosocial scores and memory recognition). While social sharing influences pleasure, and pleasure influences prosocial and memory outcomes, we did not find a direct effect of social manipulation on prosocial and memory performances. This suggests that the social sharing of music listening cannot per se modulate prosocial and encoding processes, but that socially-boosted pleasure appears pivotal and takes a facilitating role in such processes. Therefore, it becomes particularly relevant for future studies to consider the role of reward responses for the investigation of socially-driven cognitive effects. Synchronous co-attending to a stimulus with a virtual group of individuals sharing similar tastes has been shown to positively modulate affective responses and cognitive performance, such as memory.[47,64] The determinant factor of these effects has been claimed to be the perception of being part of a group,[47] which was not specifically manipulated in our experiments. Therefore, while the mere illusion of a simultaneous music listening with a group of unknown individuals online seems to be strong enough to influence the pleasure reward responses, the lack of feeling of affinity within our virtual group scenario might have hindered the possibility to find a direct modulation of prosocial and memory outcomes through the social sharing itself. Future research manipulating the information about the other group members and/or the feedback provided by the rest of the group to the participant might be pivotal to disentangle this issue and potentially observe a direct influence.

Overall, our findings revealed that socially sharing a complex emotional experience, such as music listening, can boost pleasure responses and associated social and cognitive outcomes. This opens new perspectives for the implementation of social-cognitive online paradigms that address the importance of a second-person approach to elucidate social mechanisms.[65] Furthermore, our findings offer a new angle for the study of music reward and its intrinsically social nature.[8,9,66,67] We provide an easily implementable, noninvasive, and ecological paradigm to modulate music pleasure responses able to change cognitive and social functioning, in turn offering new potential applications for music-based interventions in educational and clinical fields.

Limitations of the study

The studies presented in this article introduced a novel experimental design aiming to modulate human reward through an online *illusory* social sharing. The core concept was to show all the connected participants as pins on a map of their country of location. Results proved a significant and robust modulatory effect, confirmed by 3 studies ($N = 218$) and by an IPD meta-analysis. Nevertheless, online studies might come with some intrinsic methodological limits, particularly in participants' selection (see[68] for a comparison between lab and online experiments). Despite us employing two diverse web-testing platforms (detailed in Paradigms sections in STAR methods) and diverse recruitment strategies across two countries, it is advisable to extend the validation of this paradigm on alternative platforms and with different participant pools. Additionally, it would be also important to explore other social sharing paradigms and incorporate different kinds of materials (such as emotionally valenced images[24]) for further validation.

STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

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SUPPLEMENTAL INFORMATION

Supplemental information can be found online at https://doi.org/10.1016/j.isci.2024.109964.

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AUTHOR CONTRIBUTIONS

Experiment 1: L.F. and P.R. conceived and designed the experiment. F.C. prepared experimental material. P.R. conducted the experiment. F.C. and P.R. analyzed the data. L.F. and F.C. drafted the Experiment 1 section of the manuscript; P.R. integrated methodological details. L.F. and P.R., supervision.

Experiment 2: F.C., L.F., E.T., and F.O. conceived and designed the experiment. F.C. and E.T., prepared experimental material. F.C. and E.T. conducted the experiment. F.C. analyzed the data. L.F. and F.C. drafted the Experiment 2 section of the manuscript. L.F., supervision.

Experiment 3: L.F. and F.C. conceived and designed the experiment. F.C. prepared experimental material. F.C. and L.F. conducted the experiment. F.C. analyzed the data. L.F. and F.C. drafted the Experiment 3 section of the manuscript. L.F. supervision.

IPD Meta-Analysis: B.T., F.C., L.F., and F.O. conceived the analysis. F.C. analyzed the data. L.F. and B.T., supervision.

Integration and Review: L.F. and F.C. drafted the manuscript. F.C. created the graphics. All authors reviewed the manuscript. L.F., funding acquisition.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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STAR★METHODS

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Deposited data		
Data from the 3 experiments and IPD meta-analysis	This paper	https://osf.io/frxds/?view_only=25280f709ba4492992c7a0f73ff76c17
Software and algorithms		
oTree	Chen et al., 2016[69]	https://www.otree.org
jsPsych	De Leeuw, 2015[70]	https://www.jspsych.org/
JATOS	Lange et al., 2015[71]	https://www.jatos.org

RESOURCE AVAILABILITY

Lead contact

Further information and requests for resources should be directed to and will be fulfilled by the lead contact, Federico Curzel (federico.curzel@univ-lyon2.fr).

Materials availability

This study did not generate new unique materials.

Data and code availability

- Data reported in this paper are available at: https://osf.io/frxds/?view_only=25280f709ba4492992c7a0f73ff76c17.
- This paper does not report original code.
- Any additional information required to reanalyze the data reported in this paper is available from the lead contact upon request.

EXPERIMENTAL MODEL AND STUDY PARTICIPANTS DETAIL

Ethical statement

The study was approved by the IRB of New York University. The study was anonymous and followed the Helsinki Declaration, Convention of the Council of Europe on Human Rights and Biomedicine.

Participants

Experiment 1

Fifty-two participants were recruited (33 women, mean age: 34.72 ± 10.78 years). Data from twelve was excluded due to participants failing attention checks (see music task and procedure sections). Participants scored at least 65 in BMRQ[37] (with a score <65 indicating musical anhedonia) and did not show signs of amusia (with a score of >3 at the two amusia-related questions of the BMRQ; see[17]). Participants were located in the country where the study was conducted: USA. Forty participants (25 women; age: 36.42 ± 10.26 years) constituted the final sample of this study. They were recruited via Amazon Mechanical Turk and paid $10 for their participation.

Experiment 2

One hundred and twelve participants (62 women, 1 non-binary, mean age: 29.55 ± 6.68 years) were included in the study with the same inclusion criteria of Experiment 1 (with the only exception of Metropolitan France as the required as country of location). They were divided into three groups that were balanced in terms of individual differences in sensitivity to music reward (BMRQ questionnaire, Mas-Herrero et al., 2013) and prosocial traits (CAPRARA questionnaire,[72] and the H-H facet of the HEXACO model of personality,[73] see Table S6). Data from one participant (male) was excluded from the experiment because of technical issues. Four participants (3 women, 1 men) declared in an open comments section at the end of the experiment that they did not understand the prosocial task (Ultimatum Game), and their data were excluded only from the corresponding analysis. The final sample included 111 participants (62 women, 1 non-binary, mean age: 29.62 ± 6.67 years), divided into group 1 (*N* = 40, 25 women, mean age 30.20 ± 6.98 years), group 2 (*N* = 34, 18 women, 1 non-binary, mean age 28.29 ± 5.66 years) and group 3 (*N* = 37, 19 women, mean age 30.22 ± 7.17 years). Participants took part in the experiment on a voluntary basis, and participated in a final lottery where a voucher for hi-tech products could be won (value: €50).

Experiment 3

Seventy-five participants (59 women, mean age: 23.80 ± 4.65 years), located in the Metropolitan France territory, participated in Experiment 3 (same inclusion criteria of Experiments 1 and 2; see supplementary methods). In addition, as Experiment 3 employed classical music (see music and social stimuli section) and not participants' favorite songs as Experiment 1 and 2, we assessed participants' level of classical music liking. We included participants reporting a minimum level of appreciation of 2 out of 5 (1–5 scale, where 1 = strongly dislike and 5 = strongly like). Data from six participants were excluded because they did not finish the task, and 2 because of poor memory performance (defined with a d-prime value <0, the chance level). The final sample included 67 participants (56 women, mean age: 23.52 ± 4.44 years). Participants took part in the experiment on a voluntary basis.

METHOD DETAILS

Music and social stimuli

Experiment 1

All music stimuli were of the pop-rock genre. They consisted of music excerpts provided by participants and representing their favorite music. For each participant, we created 2 lists of 9 excerpts each: one being composed of participants' favorite songs (i.e., self-selected music), the other made by the 9 excerpts chosen by another participant (i.e., experimenter-selected music, varying across participants). Therefore, all the musical stimuli belonged to the preferred music-genre of all the participants. Three excerpts of each playlist were then randomly assigned to one of the three experimental social conditions (i.e., 6 songs for the Non-Social, 6 for the Low-Social, and 6 for the High-Social condition). Each excerpt was normalized in loudness at a maximum amplitude value of -1dB and lasted 60 s, with 5 s of exponential fade-in and fade-out. The 60 s were extracted from the original song and always comprised a part of the verse and the chorus. For the memory-attentional task, 5 s-clips were extracted from seconds 30 to 35 of the original piece.

Social stimuli consisted of different maps of the USA territory showing different pins, corresponding to the locations of virtual participants "connected" at the same time and sharing the music listening task. Three versions of the maps were created to represent the three social conditions: Non-Social (i.e., with no pins on the map), Low-Social (with 3, 4 or 5 pins), and High-Social (with 18, 19, or 20 pins; see Figure 1). Six maps with random pin numbers and locations were created for the Low- and High-social conditions. In order to maximize the credibility of the social sharing, the presentation of each map was embedded in videos simulating different steps, including the uploading of the music, the research of potential other participants and the synchronization with them through the appearance of the pins on the map.

Experiment 2

As for Experiment 1, stimuli consisted of self- (i.e., favorite) and experimenter-selected music. In order to extend the results of Experiment 1 to a broader set of music genres, we also included participants' non-preferred genres (see also[32]). To this aim, before the experiment, we asked participants to provide a list of favorite songs (also indicating the seconds corresponding to the preferred moment in each). Participants also completed a questionnaire about their musical tastes, providing their five most liked and five most disliked musical genres. We then individuated through Spotify playlists and France charts a pool of songs representative of 17 different musical genres. Then, we selected relatively unpopular songs (3 songs for each musical genre for a final library of 51 songs, see Table S7), based on a popularity index extracted through Sort Your Music, a web application by Spotify. Finally, we created a personalized selection for each participant, including 4 self-selected and 4 experimenter-selected excerpts. For the experimenter-selected songs, in order to both provide a broader range of pleasure responses and avoid participants' disfavor, we excluded the 5 most disliked genres for each subject, and then randomly extracted 4 excerpts from the list of the remaining genres. Therefore, the musical selection varied across subjects, who were in this way exposed to a different set of music styles including both preferred and non-preferred music genres. Importantly, the songs were selected to balance the items across subjects and experimental conditions (i.e., Non-Social, Low-Social, High-Social), being also balanced for their musical features (tempo, energy, danceability, valence and popularity, ratings extracted using Sort Your Music; see Table S8).

Social stimuli were structured as for Experiment 1, with two differences: the maps were showing the Metropolitan France territory (i.e., the country of residence of participants), and the number of pins in the social conditions was slightly different (Low-Social with 10 ± 3 pins; High-Social with 20 ± 3 pins) (see Figure 2).

Experiment 3

Music stimuli consisted in unfamiliar instrumental classical music excerpts suitable for music memory tasks previously validated by Ferreri & Rodriguez-Fornells[17] (see also[16,19]). The stimuli included 48 excerpts, further divided into four playlists of 12 pieces each, and balanced for general pleasantness, arousal, valence, and familiarity (see Table S11). As the excerpts were preselected for being unfamiliar, if participants reported some familiarity with an excerpt item greater than 50 (1–100 familiarity scale) data for that trial was selectively excluded from the analyses further reported for that participant.[16] For each excerpt, two versions differing in duration were created: a 20 s version for the music task and a 10 s version for the memory task. The excerpts were normalized (-1dB) and faded in and out (3 s).

Social stimuli consisted in the same maps of Experiment 2 (i.e., Metropolitan France territory). For experimental reasons due to the inclusion of the memory task and the amount of the to-be-encoded material, only Non-Social (0 pins) and Social (i.e., 10 ± 3 pins) conditions were employed in Experiment 3.

Music task

Experiment 1

Each participant listened to 18 songs total (self- or experimenter-selected songs; see music and social stimuli section). After listening to each excerpt, they provided through a 0–100 scale slider subjective ratings of the overall pleasure felt during the musical piece (from no pleasure to intense pleasure), as well as other affective control subjective ratings, i.e., beauty (from no beauty to great beauty), interest (from no interest to great interest), valence (from very sad to very happy), and familiarity (from completely unknown to very familiar). Participants could not control the music player (e.g., they could not skip to the song ending). In response trials, participants were not able to advance to the next page unless all answers had been provided. Participants further completed a memory-attentional task devised to assess whether they were paying attention. After each providing the behavioral ratings, participants heard 5 s of a musical piece. The presented clip was part of the song they just heard in half of the occasions. In the other half, the 5 s excerpt was part of another song presented during the experiment. Participants had to indicate whether the clip was part of the song just presented or not. Using these responses, a d-prime measure was calculated for each participant. Data from participants with d-primes lower than 1 were excluded as that score is indicative that the participant was not really paying attention to the music played (see[74] for a similar measure).

Experiment 2

To extend previous observations and monitor the pleasurable responses also during music listening, we additionally asked participants to provide continuous pleasure ratings. That is, during each excerpt, participants reported through a slider showing a 0–100 scale, in real-time, the pleasure felt while listening to music (from no pleasure to intense pleasure), acquired at a 2 Hz (sampling rate).

Experiment 3

In order to avoid distractions during the encoding of the auditory material, no continuous ratings were provided while listening to music (as done in Experiment 2). After listening to each excerpt, participants provided through 0–100 scale slider subjective ratings of the overall pleasure felt during the musical piece (from no pleasure to intense pleasure), as well as other subjective ratings (as in Experiment 1 and 2).

Prosocial tasks (Experiment 2 only)

To investigate prosocial behaviors, two classical socio-economic games (Ultimatum game,[39] Dictator game[38]) were adapted to a virtual scenario where participants (as in the music task) believed that behind the icon of a virtual partner a real person was connected and playing at the same time.

In the typical Ultimatum game, one of the two players is a “proposer” (i.e., someone who makes money offers) and the other a “receiver” (i.e., the one who receives the money offers). During 10 trials, the proposer is required to divide a specified amount of money with the receiver by proposing an offer. The receiver has the choice to either accept the offer, leading both parties to win the amount, or reject the offer, thus leading both to lose the amount. Here, all participants were designed as proposers cumulating coins that increased their probability to win the final prize of the experiment (i.e., a €50 voucher). Automated responses were programmed for the virtual receiver so that the offer’s probability acceptance rate was proportional to the increasing value of the offer. At the end of the game, participants saw how many coins make them likely win the final lottery they cumulated. The Ultimatum game’s goal was to trigger a dilemma on the choice of a more prosocial attitude or a more selfish attitude: the higher the amount of the offer, the higher the prosocial behavior.

The Dictator game is typically played between two participants, in which one is designated as a “dictator” and the other as the “receiver”. The dictator is given an amount of money and is asked to decide how much, if any, to donate to the receiver (it is also allowed not to donate anything). In this case, differently as in the Ultimatum Game, the receiver passively collects the dictator’s split endowment without any possibility of action in return. Here, as done by Bekkers,[75] we adapted this game to a specific scenario. Namely, we asked participants whether, in the eventuality of winning the final lottery (i.e., a €50 voucher), they would donate part or the entire amount to an association. If participants answered yes, they had to provide additional choices, deciding how much of the total amount they would donate (5 options: €10, €20, €30, €40, €50), and to which associations (6 options of voluntary/humanitarian/environmental and animal protection associations, or a free space for a name of a proposed association). In the same line and as a further prosocial measure, we asked participants if they would be available to help us and continue with another phase of the study and, if yes, for how long (4 options: 0, 5, 10, 20 min; see[76]).

Interference tasks (Experiment 3 only)

After the music task, participants were asked to complete two interference tasks: a Flanker task[70] and a Reaction Time task.[71] The first consisted in the presentation of a central target stimulus (an arrow pointing left or right) surrounded by distractors (arrows pointing either in the same or opposite direction, e.g., congruent, or incongruent). Following this, participants were asked to respond as quickly and accurately as possible to the direction of the target arrow by pressing a corresponding key. The second task consisted in encoding the pairing between three colors and keys and in responding to a stimulation (a color) by pressing the corresponding key. The interference phase lasted around 10 min.

Memory task (Experiment 3 only)

During the memory test (recognition/recollection paradigm[40]; Figure 3), participants listened to the 24 old music excerpts and 24 new music excerpts, each one lasting 10 s.[17] For each excerpt, participants were asked to indicate whether they had listened to it before (old-new recognition task). In case of an affirmative answer, they had to make one additional choice among three: Remember (R), Know (K) or Guess (G). R means that the participant can retrieve specific information in relation to the moment of listening; K means that the excerpt sounds very familiar, but participants cannot recall the full details; G means that the answer was given without being sure that the excerpt had been presented previously (recollection task[40]). Finally, in case of an affirmative answer, they were also asked to indicate in which condition they thought they previously listened to the excerpt (Non-Social, Social, I don't remember; source memory task).

Procedure

Experiment 1

This experiment was coded using *oTree*, a platform for the development of controlled online behavioral experiments.[69] The experiment was presented to participants as an HTML webpage within Amazon Mechanical Turk. In a first recruitment phase, participants had to complete an online version of the BMRQ, which included an attentional check (e.g., *Please, select the option "Agree"*) and to provide a list of their 9 favorite songs. Their songs were purchased and included in the main experiment. A week after the first phase, an invitation to complete the main experiment was sent to the participants via Amazon Mechanical Turk's API. Participants were first presented with an informed consent page and, upon acceptance, with detailed instructions for the experiment. Each participant was asked to be in a calm and comfortable room and wear headphones in order to take part in the experiment. Before starting the music task, participants checked the quality of the audio with a trial audio-file and adjusted the volume accordingly. Another trial audio-file was employed to calibrate the slider through which participants were required to report subjective affective ratings (see music task section).

The study was described as a national experiment conducted by a research team working overall the USA. Participants were told that other people were taking part in the experiment at the same moment, that the people doing the experiment with them would be shown in each trial as pins on a map (i.e., with each pin representing the virtual listener in their city of residence; see Figure 1), and that the number of people listening to the same song in each trial with them would vary and that sometimes no-one would be listening to music with them (represented as a map with no pins on it). Participants listened to self- (i.e., favorite) or experimenter-selected pop-rock music (18 music excerpts in total, 9 for each music category) in three conditions: alone (Non-Social), with a small group of people (Low-Social), and with a larger group of people (High-Social; see music and social stimuli for details). Unbeknownst to them, there were no real people connecting to each of the trials. Therefore, participants had the illusion of sharing a collective listening experience, without the possibility to interact with others. The association of the excerpts to each social condition, as well as the order of the social condition, were respectively randomly chosen and counterbalanced. After each excerpt, the map disappeared, and participants were asked to provide subjective ratings about the listened excerpt (see music task section). After this, a new trial was presented. After completing the task, participants were free to leave any comments about the experiment. The entire experimental procedure lasted about 45 min.

Experiment 2

The whole experiment took part online. It was programmed on jsPsych's library,[77] and run on a private server of the laboratory using JATOS.[78] Before taking part in the experiment, participants were required to fill a questionnaire to assess whether they met the inclusion criteria and obtain information about their musical taste (i.e., most liked and disliked musical genres, see music and social stimuli section). Selected participants were then recontacted, a day and a time of connection were scheduled with the experimenter. In this way, they could more easily believe that other people were connecting at the same time for the same task. A link redirecting to the experiment's HTML page was sent at the scheduled day and time. As in Experiment 1, participants adjusted the volume of the audio and calibrated the slidebar before the beginning of the tasks.

Similarly to Experiment 1, participants were asked to listen to and rate musical excerpts (8 in total, 4 self- and 4 experimenter-selected) in one of the following experimental conditions: listening to music alone (Non-Social), with a small group of people (Low-Social), or with a larger group of people (High-Social). In addition to the subjective ratings reported after each excerpt, participants were also asked to provide a continuous pleasure score indicating the pleasure felt in real time during each excerpt (see music task section for details).

After the music task, which lasted about 15 min, participants completed the prosocial tasks (i.e., the adapted versions of Ultimatum and Dictator games, see prosocial tasks (experiment 2 only) section; see Figure 3). As was the case for the music task, participants had the illusion that they were connected with another person at the same time. The prosocial tasks lasted about 15 min. After completing the task, participants were free to leave any comments about the experiment.

Experiment 3

The experiment was programmed and run on same library and server as in Experiment 2. As for Experiment 2, participants were first required to fill a questionnaire to assess whether they liked classical music. Selected participants were then recontacted following the same procedure as in Experiment 2. The setup (i.e., audio volume adjustment and slidebar calibration) and the music task were the same as in Experiment 1, with the exception that participants listened to and rated unfamiliar classical music excerpts in only two social conditions: alone (Non-Social) and with a small group of people (Social). Participants listened to a total of 24 excerpts constituting the encoding phase (12 for each social condition; see music and social stimuli, Tables S11 and S12). The music task took about 25 min to complete.

After the music task, participants went through an interference phase (Interference tasks (experiment 3 only) section), which lasted about 10 min, and then completed a memory test. Participants were asked to listen to 24 old and 24 new music excerpts and perform for each one a recognition/recollection and source memory paradigm[40] (Figure 3; memory task (experiment 3 only), music and social stimuli section). The order of the old and new playlists was counterbalanced across participants. The memory task lasted about 15 min. After completing the task, participants were free to leave any comments about the experiment.

QUANTIFICATION AND DATA ANALYSIS

Statistical analyses

Experiment 1

We analyzed data using linear mixed modeling and a forward selection approach in order to construct the most suitable model for our analyses. This involves systematically adding predictor variables to the null model, considering both statistical significance and model fit. The Restricted Maximum Likelihood (REML) method was used for estimation of the model parameters. To assess the significance of each predictor, we conducted likelihood ratio tests (LRT) and evaluated the resulting *p*-values. Additionally, we utilized the Bayesian Information Criterion (BIC) as the main criterion for model choice, aiming to strike a balance between model complexity and goodness of fit. The BIC allowed us to compare the competing models and select the one including at least our main variable of interest (i.e., Social Condition when predicting Pleasure ratings) with the lowest value. We therefore adopted a both theory- and data-driven approach that led us to identify the most relevant predictors and construct a final model that best explained the variation in the outcome variable. The tested models included a random intercept for each participant and Social Condition (Non-Social, Low-Social, High-Social), Song Category (favorite songs and experimenter-selected songs), and individual differences in music reward sensitivity (BMRQ score) as predictors. Additionally, Gender was included as a predictor to account for sample composition. We tested both their fixed effects and interactions, following an order of predictor appearance guided by our hypotheses. Gender was not tested in interaction, as we did not have a specific hypothesis regarding a potential direct relationship with other predictors. Participants' overall pleasure ratings (i.e., the ratings provided after each trial) were considered as dependent variable of interest (see Table S1 for model selection). The normality of the distribution of Pleasure ratings was assessed with skewness (−0.67) and kurtosis (2.73) values, revealing an approximately normal distribution. The best fitting model was employed with the same fixed factors for predicting other control subjective measures (i.e., Beauty, Valence, Interest, and Familiarity). We used type 3 Wald chi-squared tests to evaluate the statistical significance of fixed effects in the final linear mixed effects models. This approach allowed us to examine the unique contribution of each predictor variable while controlling for the effects of other covariates. We employed both marginal ($R^2_{(m)}$) and conditional ($R^2_{(c)}$) R^2 values as indicators of the goodness-of-fit for the final 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.[79] The intra-class correlation coefficient (ICC) was calculated to quantify the proportion to which the variability in the outcome variables can be attributed to differences between participants (captured by the random intercept in the models). The generalized variance inflation factor (GVIF) was used to detect eventual multicollinearity issues in the fixed effects predictors of the model. A rule of thumb is that if the GVIF value is greater than 2.5, it suggests that there might be multicollinearity issues. The normality of the distribution of the residuals from the model was assessed with a Q-Q plot (see Figure S1). Post-hoc Tukey-corrected pairwise comparisons were conducted in case of significant effects of Social Condition. The analyses were carried out using *lme4*, *emmeans, lmtest, MuMIn,* and *car* packages in R (version 3.3.0).

Experiment 2

The same analytical approach of Experiment 1 was employed to investigate the effect of the Social Condition on the reported Pleasure overall and Continuous Pleasure (i.e., the average of the continuous ratings provided during the listening of each excerpt). The normality of the distribution of Pleasure ratings was assessed with skewness (-0.93) and kurtosis (3.40) values, revealing an approximately normal distribution. To test the effect of the Social Condition and Pleasure (main varibales of interest) on Ultimatum's Game offers, we fitted linear mixed models with the same forward selection approach presented above (see Table S3 for model selection).

Linear regression analyses were run for the two adapted Dictator games, with Donation amount and Time availability amount as the predicted variables, Social Condition and Pleasure (overall or continuous) as predictors (as in the model used to predict Ultimatum's Game offers). For the Pleasure variable, in all the analysis on prosocial outcomes, we computed the mean values of overall and mean continuous ratings on all the trials per participant. As for Experiment 1, ICC and GVIF scores for the mixed effects models were computed, normality was assessed with a Q-Q plot on residuals (see Figure S1), and post-hoc Tukey-corrected pairwise comparisons adopted in case of significant effects of Social Condition. The analyses were carried out using *lme4*, *emmeans*, *lmtest, MuMIn,* and *car* packages in R (version 3.3.0).

Experiment 3

The same analytical approach of Experiment 1 and 2 was employed to investigate the effect of the Social Condition on the reported Pleasure (see Table S4 for the model selection). The normality of the distribution of Pleasure ratings was assessed with skewness (-0.24) and kurtosis (2.85) values, revealing an approximately normal distribution.

In order to test the effects of Social Condition and Pleasure (main variables of interest) on memory, we used the same approach of Experiment 2 (i.e., for prosociality scores). For both Recognition, Recollection, and Source Memory performance, the dependent variable was assumed to have a binomial distribution, and a logit link function was applied. For Recognition, the dependent variable was whether each old excerpt was correctly recognized or not (i.e., forgotten); for Recollection, the dependent variable was whether each old, correctly recognized excerpt was categorized as remembered or not[16]; for Source Memory, the dependent variable was whether each old, correctly recognized excerpts were correctly associated or not with the social encoding context (i.e., Non-Social or Social condition).

As for Experiments 1 and 2, ICC, GVIF scores, and a normality test (i.e., Q-Q plot; see Figure S1) were computed for the chosen (generalized) linear mixed models. The analyses were carried out using *lme4*, *emmeans*, *lmtest, MuMIn,* and *car* packages in R (version 3.3.0).

Details of the meta-analysis of individual participant data

A further meta-analysis of Individual Participant Data (IPD[41]) was conducted to check the robustness of the effect of Social Condition (main variable of interest) on Pleasure ratings. To this aim, data from the three experiments (Experiment 1, $N = 40$; Experiment 2, $N = 111$; Experiment 3, $N = 67$) were combined into a single data frame. This included 218 participants (143 women, mean age: 29.00 ± 8.22 years). Considering the different number of social conditions across the three experiments, only two social conditions were examined: Non-Social and Social. This was done by merging Low-Social and High-Social conditions in Experiment 1 & 2. A linear-mixed effect modeling, with forward selection approach was employed to determine the best model to predict Pleasure ratings (see Table S5). Random intercepts were used to account for intra-Subject variability and Experiment-specific effects, and the intraclass correlation coefficient (ICC) was computed. GVIF scores were also computed for the chosen linear mixed model. The analyses were carried out using *lme4*, *emmeans*, *lmtest, MuMIn,* and *car* packages in R (version 3.3.0).