Physical exercise increases perceived musical pleasure: Modulatory roles of arousal, mood, or
dopamine?

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Abstract

Music's ability to influence exercise performance is well known, but the converse, how exercise influences music listening, remains largely unknown. Exercise can elevate arousal, mood, and neurotransmitters including dopamine, which are involved in musical pleasure. Here we examine how exercise influences music enjoyment, and test for a modulatory role of arousal, mood, and dopamine. Before and after exercise (12 min of vigorous running) and a rest control session, participants ($n=20$) listened to music clips and rated their enjoyment and subjective arousal; we also collected mood ratings and eye-blink rates, an established predictor of dopamine activity. Ratings of musical enjoyment increased significantly after running, but not after the rest control condition. While changes in subjective arousal ratings did not differ between run and rest days, change in subjective arousal correlated with change in music enjoyment. After running, the change in music enjoyment had a positive but non-significant correlation with change in eye-blink rates ($r=.36$). Positive mood increased more after exercise than after the rest control session, but the change in positive mood did not correlate with change in music enjoyment. In sum, exercise leads to increased musical pleasure, and this effect was related to changes in arousal.

Keywords: Exercise, music perception, aesthetics, dopamine, pleasure, mood, arousal

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Music's ability to improve exercise performance is well established (e.g., Karageorghis, 2016); but the converse, how exercise influences music listening, remains largely unknown. Exercise leads to many physical and psychological effects, including short-term boosts in arousal, mood, and neurotransmitters including dopamine. Since these are implicated in perceived musical pleasure, exercise could plausibly boost musical pleasure. Here we test whether exercise leads to increased musical pleasure, and test for a modulatory role of arousal, mood, and dopamine.

Predictors of musical pleasure

Music is universal across cultures and can evoke profound pleasure (Blood & Zatorre, 2001; Chanda & Levitin, 2013). Musical pleasure relates to properties of the music including complexity, expectation, and familiarity (e.g., Wundt, 1874; Huron, 2006; Meyer, 1956), and most aesthetic research focuses on such musical properties (Brattico & Pearce, 2013; Finnäs, 1989). However, the aesthetic experience also depends on the listening situation and listener's state (Hargreaves & North, 2010).

Several psychological and physiological factors influence an individual's experience of musical pleasure (e.g., Brattico & Pearce, 2013). A factor that has long been linked to pleasure is arousal. A prominent theory of music aesthetics proposes that an important source of pleasure is the potential of the stimulus to increase psychobiological arousal to a moderate level (Berlyne, 1971). Arousal and activity of the autonomic nervous system predict music preferences and liking for music (Hargreaves & North, 2010). While much work in this area focuses on how music influences the listener's state of arousal, changes in arousal by other means can also affect music liking and preferences. Music enjoyment was shown to increase after inducing physiological arousal through a self-focused attention task (Schäfer & Sedlmeier, 2011). Another

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way to modulate arousal is through exercise. One study that looked at musical preference after exercise showed that after exercise, people preferred low-arousal music (i.e., slow and quiet), whereas after relaxation, people preferred high-arousal music (i.e., fast and loud); these complementary preferences show that music can be used to moderate physiological arousal (North & Hargreaves, 2000).

Musical pleasure is also modulated by the brain's reward circuitry and the neurotransmitter dopamine. Music perceived as highly emotional engages the reward system, including the ventral striatum, which also responds to non-musical stimuli like food and sex (Blood and Zatorre, 2001). The degree of musical pleasure correlates with the degree of activity in the striatum (Berns, Capra, Moore, & Noussair, 2010; Koelsch, 2014; Salimpoor, van den Bosch, Kovacevic, McIntosh, Dagher, & Zatorre, 2013). Additionally, modulating the reward system and dopamine availability with transcranial magnetic stimulation or dopaminergic drugs leads to changes in perceived musical pleasure (Mas-Herrero, Dagher, & Zatorre, 2018; Ferreri et al., 2019). Here we take a more naturalistic approach that could potentially modulate reward activity and musical pleasure, namely exercise.

Exercise, mood, and dopamine

Exercise produces many psychological and physical effects, including elevated mood and concentration of neurotransmitters such as dopamine (Heijnen, Hommel, Kibele, & Colzato, 2016). Several studies demonstrate that even a single bout of exercise can lead to more positive mood, higher ratings of happiness, or the “runner's high” (Boecker et al., 2008; Yeung, 1996). While the runner's high has been linked to endorphins (Boecker et al., 2008) and cannabinoids (Fuss et al., 2010), exercise can lead to changes in other neurotransmitters including dopamine (Foley & Fleshner, 2008; Heijnen et al., 2016).

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In extensive animal literature, physical activity consistently leads to increased dopamine content and release (reviewed in Foley & Fleshner, 2008). In humans, links between exercise and dopamine are less clearly established. A single study on dopamine transmission using PET did not observe changes in striatal dopamine concentration after treadmill running (Wang et al., 2000). Conversely, some studies report increased peripheral dopamine levels after physical exercise (Koch, Johansson, & Arvidsson, 1980; Musso, Gianrossi, Pende, Vergassola, & Lotti, 1990). After intense treadmill exercise, boys had increased dopamine levels as indicated by higher spontaneous eye blink rates (EBR) (Tantillo et al., 2002). Spontaneous EBR has been established as a non-invasive predictor of dopamine function, with higher EBR indicating higher dopamine function (Jongkees & Colzato, 2016; Karson, 1983; cf. Dang et al., 2017). In light of overwhelming evidence for dopamine-exercise links in non-human mammals (Foley & Fleshner, 2008), and conserved dopaminergic physiology across mammals (Barron, Søvik, & Cornish, 2010), an exercise-dopamine link is possible in humans and warrants further study.

Experimental Overview

In this study, we examined the effects of exercise on music enjoyment, and test for a modulatory role of arousal, mood, and dopamine. Before and after treadmill running and a rest control session, participants rated their enjoyment of unfamiliar music clips, their subjective arousal, their positive and negative affect (PANAS questionnaire), and we collected spontaneous EBR. We predicted that exercise would lead to increases in perceived musical enjoyment, subjective arousal, positive mood, and possibly EBR, and that the change in musical enjoyment would correlate positively with changes in arousal, positive mood, and EBR. This research could improve understanding of how musical aesthetics is affected by exercise, and more generally, by the listener's psychological and physiological state.

Methods

Participants

Twenty undergraduate students (8 males, 12 females; age range = 19-25 years) participated in this study. Participants reported exercising regularly in various activities including running (n=16), weight lifting (n=14), martial arts (n=2), yoga (n=2), soccer (n=1), swimming (n=1), and tennis (n=1). The mean number of exercise sessions per week was 4.2 (SD = 1.0, range 1-6); and the mean hours of exercise per week was 5.8 (SD = 2.5, range = 2-9). Amount of exercise did not correlate with musical enjoyment, arousal, mood, or EBR. Participants reported no hearing impairments and no history of cardiovascular, neurological, or psychiatric disorders that would affect their participation. All participants provided informed consent. After completion of the study, participants were compensated with extra credit or money (\$10/hour). The study was approved by the local IRB.

Procedure

Overview. The study consisted of two one-hour sessions separated by one week. Each session consisted of music ratings, questionnaires, and eye-blink recordings before and after an exercise task (12 minutes of vigorous running) or control task (listen to podcast while seated). Exercise and control days were counterbalanced in order.

Music rating task. Participants listened to 30 second music clips and rated each on enjoyment and arousal. The stimuli were 48 song clips selected from stimuli used in Salimpoor et al. (2013). The music was unfamiliar (as corroborated by subject ratings) and included a variety of genres including rock, indie, and electronic. The 48 clips were separated into four groups of 12 songs that were matched on ratings (from Salimpoor et al., 2013), tempo, genre,

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and energy-level. Song energy was determined subjectively based on factors such as tempo and percussiveness prior to the experiment; 20 songs were high energy, 18 medium energy, and 10 low energy. Participants rated 24 songs (2 groups of 12 songs) presented in random order before and 24 songs after the exercise and control tasks. Over the course of the two sessions, subjects heard each group of songs twice (some before and some after; order was counterbalanced across run and rest days). There were no effects of song group indicating appropriate balance, and in addition, individual songs were included in linear mixed effects models to account for any effects of individual songs.

After each clip, participants responded via mouse click to questions on the computer screen:

- “How much did you enjoy that song?” [100 point slider scale with anchors “Hated it” and “Loved it!”]
- “Rate your subjective arousal while you were listening.” [100 point slider scale with anchors “Calm” and “Very Excited”]
- “Was that song unfamiliar or familiar?” [two response boxes labelled “Unfamiliar” and “Familiar”]

The experiment was run on a desktop computer (HP Z400, LE2201w monitor on Windows 7 Pro), running MAX/MSP (San Francisco, Cycling ‘74), and songs were presented over speakers (Mackie MR8mk3 powered studio monitors).

PANAS questionnaire. Participants rated their current feelings and emotions on the 20 item Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) before and after the run and control tasks. The PANAS is valid and reliable for assessing mood (Crawford & Henry, 2004). The 10 positive and 10 negative words were rated on a 1-5 scale

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(1=Very Slightly or Not at All; 5 = Extremely), and summed respectively for composite positive and negative mood scores.

Eye-blink rates. Spontaneous eye blinks were collected using an EOG pod and LabChart software (AD Instruments, New Zealand), and adhesive (Ag/AgCl) electrodes placed above and below the right eye with a ground electrode placed on the neck. Each recording was 4 minutes long (Slagter, Georgopoulou, & Frank, 2015). Subjects sat in a comfortable position, looked at a fixation point on the wall about three feet away (Colzato, van den Wildenberg, van Wouwe, Pannebakker, & Hommel, 2009), and were instructed: “simply look at the wall in front of you, and please do not move your head or activate your facial muscles.” Spontaneous EBR are stable during the day but increase in the evening (Barbato et al., 2010), so no data were collected after 5pm, and each subject’s two sessions (one week apart) occurred at the same time of day.

Eye blink data were analyzed using a combination of automated and manual techniques. A peak-picking algorithm in Matlab (Yoder, 2011) identified local maxima in voltages. The peak-picking procedure was manually screened to ensure accuracy in eye-blink detection, and epochs with excessive noise or drift were removed. Two independent raters had a high degree of consensus ($r > .8$). Eye-blink data from 4 subjects could not be analyzed due to excessive noise ($n=2$) and missing data from the entire session ($n=2$), leaving useable eye-blink data from a final sample of 16 subjects; two additional subjects were missing data on a single pre-test session, leaving $n=14$ for the rest day.

Exercise and control task. After the pre-test tasks, participants ran on a treadmill for 12 minutes or listened to a podcast. In the run condition, participants ran for 6 minutes at a constant speed, followed by 6 minutes at increasing speeds (i.e., 6 discrete one-minute intervals that increased 0.3 mph every minute). We selected short intense running in light of Winter et al.

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(2007) showing steeper trends in peripheral dopamine (and learning) after intense accelerating running than after moderate low-impact running. Participants selected their initial speed and decided if they could handle each interval speed increase or if they preferred to remain at the same speed—17 participants completed all 6 speed increases; the other three participants completed 5, 3, and 0 speed increases, respectively. All participants completed the entire 12 minutes of running. After running, participants rated their perceived exertion (Borg, 1982). Exertion ratings averaged 13.9 (SD = 1.7) corresponding to “somewhat hard” exertion. Exertion ratings were similar across subjects, and did not correlate with change in music enjoyment, EBR, arousal, or mood. In the control condition, subjects remained seated at the computer and listened to a podcast from The Moth (<https://themoth.org/stories/speedy-delivery>).

Data Analysis. Experimental effects were analyzed in two ways. In the first approach, we used standard hypothesis testing, averaged each subject’s ratings over songs, and examined pre-to-post changes (in ratings, EBR, and mood) on exercise and control days using t-tests, ANOVA, and correlation. In the second approach, we use linear mixed effects (LME) models to predict ratings as a function of condition.

In the first approach, to account for individual differences, we computed change in ratings from pre-to-post session as our main measures of ratings. Pre-to-post changes were assessed with t-tests between conditions and against zero to look for significant changes from pre-to-post, ANOVA with factors (session and song energy), and were correlated with other predictors. Analyses were performed with SPSS 26. Data were scanned for outliers and assessed for normality. One cell (~0.4% of the data) was identified as an extreme outlier (greater than the third quartile by more than 3 times the interquartile range; Tukey, 1977); that value was truncated to the next highest value in that condition+1 (Barnett & Lewis, 1994). The assumption

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of normality was violated (Shapiro-Wilk test, $p < .05$) in one variable (change in the PANAS negative scale on the control day); inspection of those scores showed that most clustered around the mean with one low and one high extreme value (not extreme outliers). Those values were Winsorized to be one unit beyond the next most extreme value, and subsequently met the assumption of normality.

In the LME approach, we used RStudio (v1.2.1335, R Core Team, 2015) and the *lmer* function from the package *lme4* (Bates et al., 2015) to perform a linear mixed effects analysis of the relationship between ratings and condition. The LME models were run on the raw (unaveraged) ratings from every trial and included fixed effects for the experimentally manipulated factors condition (Run, Rest), Time (Pre, Post), and their interaction, and random (intercept) effects for subject and song. Residual plots revealed no deviations from homoscedasticity or normality. The models were assessed using likelihood-ratio tests that compared the full model against a reduced model without the effect in question (Winter, 2013).

Results

Ratings

Music enjoyment ratings increased significantly from pre-to-post on the run day ($M = 4.6$, $SD = 6.4$), $t(19) = 3.19$, $p = .005$, $d = .71$, but did not change from pre-to-post on the control day ($M = 0.3$, $SD = 4.9$), $t(19) = 0.26$, $p = .80$, $d = .06$. We analyzed the pre-to-post change in music enjoyment in a two-way repeated measures ANOVA with the factors session (run, rest) and song energy (high, mid, low). The change in music enjoyment was significantly greater on the run day than the rest day, $F(1,19)=7.06$, $p = .016$, $\eta_p^2 = .27$. There was no significant main effect of song energy, $F(2,38) = 2.10$, $p = .14$, $\eta_p^2 = .10$. There was no interaction between

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session and song energy, $F(2,38) = .37$, $p = .69$, $\eta_p^2 = .02$; this lack of interaction indicates that the increase in enjoyment after running was consistent for up-beat, moderate, and mellow songs (Figure 1).

Figure 1. Pre-to-post change in enjoyment ratings for vigorous running and rest control conditions separated for the high-, mid-, and low-energy songs. Results show increased music enjoyment after run, but not after rest, for all levels of song energy. Error bars represent ± 1 standard error.

In addition to enjoyment, participants rated their subjective arousal (from calm to excited) that they experienced while listening to each song. Participants did not report feeling a larger increase in arousal after running compared to after the rest control, as pre-to-post change in arousal did not significantly differ between the run day ($M = 3.12$, $SE = 1.26$) and the control day ($M = 2.07$, $SE = 1.34$), $t(19) = 0.56$, $p = .59$, $d = .12$.

Exercise led to a greater increase in positive mood than the control condition. The pre-to-post change in PANAS-positive mood ratings was significantly higher on the run day ($M = 2.05$, $SE = 1.52$) than on the control day ($M = -4.20$, $SE = 1.16$), $t(19) = 3.69$, $p = .002$, $d = .82$. For the

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change in PANAS-negative mood, no difference occurred between the run day ($M = -2.05$, $SE = 0.73$) and the control day ($M = -2.10$, $SE = 0.44$), $t(19) = 0.06$, $p = .95$, $d = .01$.

Eye Blink Rates

The pre-to-post change in eye-blink rates did not differ between the run day ($M = -1.00$, $SE = 0.75$) and the control day ($M = -0.94$, $SE = 0.72$), $t(13) = 0.05$, $p = .96$, $d = .01$.

Relationship between Musical Enjoyment, Arousal, Eye Blink Rates, and Mood

On the run day, the pre-to-post change in music enjoyment significantly correlated with change in arousal ratings taken after each song, $r(18) = .73$, $p < .001$ (Figure 2, upper left panel). The change in music enjoyment had a positive but non-significant, correlation with the change in eye-blink rates, $r(14) = .36$, $p = .17$ (Figure 2, lower left panel). Change in music enjoyment did not correlate with change in positive mood, $r(18) = .00$, $p = .99$, or change in negative mood, $r(18) = -.22$, $p = .34$.

On the rest day, the pre-to-post change in music enjoyment significantly correlated with change in arousal ratings, $r(18) = .55$, $p = .012$ (Figure 2A, upper right panel). The pre-to-post change in music enjoyment did not correlate with the change in eye-blink rates, $r(12) = -.24$, $p = .40$, change in positive mood, $r(18) = .03$, $p = .90$, or change in negative mood, $r(18) = .30$, $p = .19$.

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A

B

Figure 2. Scatterplots showing the relationship between pre-to-post change in music enjoyment ratings and A) pre-to-post change in subjective arousal ratings while listening to song clip, and B) pre-to-post change in Eye Blink Rates.

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Linear Mixed Effects Models

The LME models on unaveraged ratings that considered effects of individual songs showed similar effects of exercise on music enjoyment. The likelihood-ratio tests revealed that music enjoyment ratings were predicted by Session (Run/Rest), $\chi^2(1) = 19.27$, $p < 0.001$, and Time (Pre/Post), $\chi^2(1) = 3.66$, $p = 0.056$. The interaction between Session (Run/Rest) and Time (Pre/Post) was a significant predictor, $\chi^2(1) = 6.51$, $p = 0.011$. *Post hoc* analyses on the run day showed that time (Pre/Post) affected ratings, $\chi^2(1) = 7.17$, $p = 0.007$, with ratings after running increasing by 3.88 points ± 1.44 (standard errors). On the rest day, time (Pre versus Post) did not affect ratings, difference = 0.49 points ± 1.52 standard errors, $\chi^2(1) = 0.10$, $p = 0.75$.

Discussion

This study demonstrates that exercise leads to increased musical pleasure. After running vigorously for 12 minutes, participants rated music as more enjoyable. The increase in enjoyment was significantly larger on the run day than the rest control day. Enjoyment increased for up-beat, moderate, and mellow songs, indicating a general boost in experienced musical pleasure, rather than a change in preference for music that matched or moderated participants' physiological arousal. Increased musical pleasure after exercise underscores the importance of the listener's state on aesthetic perception (Hargreaves & North, 2010).

We measured several factors that could potentially relate to changes in musical pleasure. The factor showing the clearest link to the increased musical pleasure was subjective arousal (rated on a scale from "calm" to "very excited" after hearing each song clip). The pre-to-post changes in arousal ratings were similar for the Run and Rest days. However, the pre-to-post change in arousal correlated with pre-to-post change in enjoyment for both the rest and run sessions—participants who rated themselves as more "excited" also rated the music as more

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enjoyable. Individual differences in how running and the podcast impacted the listener's state of arousal (e.g., from energized to fatigued) related their enjoyment of the music. This observed relationship between arousal and musical enjoyment accords with extensive literature linking arousal and musical pleasure (Berlyne, 1971; Brattico & Pearce, 2013; Hargreaves & North, 2010).

Based on established links between musical pleasure and dopamine (e.g., Salimpoor et al., 2013; Mas-Herrero et al., 2018) and possibly between exercise and dopamine (e.g., Foley & Fleshner, 2008), we tested if a link between musical pleasure and exercise was modulated by dopamine. Overall, exercise did not lead to an increase in the eye-blink rate dopamine marker. In spite of no overall effect of exercise on eye-blink rate, individuals' changes in eye-blink rate could relate to their changes in musical ratings. Here the change in musical enjoyment after exercise did not significantly correlate with change in eye-blink rate. The observed correlation coefficient ($r = .36$), however, is considered a moderate correlation (Taylor, 1990), and does not fully discount dopamine's role in how exercise modulates musical pleasure. Future research, without this study's limitations of sample size and indirect measure of dopamine (recently questioned by Dang et al., 2017), could further evaluate the modulatory role of dopamine in exercise's effect on musical pleasure.

A variety of neurotransmitter systems are involved in music listening and pleasure (Chanda & Levitin, 2013). Exercise is less specific to the dopamine system than targeted neuromodulation, as exercise also relates to changes in hormones and other neurotransmitters, including endorphins, endocannabinoids, and serotonin (Heijnen et al., 2016). Increased musical pleasure after exercise could be modulated by any number of unmeasured mediators. Here we focused on a measure of dopamine, but future studies could investigate modulatory roles of other

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brain chemicals (note that separating neurotransmitter systems can be challenging; Chanda & Levitin, 2013).

Another potential moderator between exercise and musical pleasure is mood. We measured positive and negative mood with the PANAS. Participants' pre-to-post change in positive mood was significantly greater on the run day than on the rest day. This change in positive mood aligns with previous literature showing that exercise can improve mood (e.g., Yeung, 1996). But change in positive mood did not correlate with music enjoyment ($p=.9$), suggesting that increased musical pleasure after exercise was not due to improved mood.

Future Directions and Conclusions

The present study analyzed effects of vigorous running on musical pleasure. Future studies could explore if other types and amounts of exercise result in similar effects. The majority of our participants exercised regularly; future work could include participants at a range of fitness levels to examine whether exercise boosts musical pleasure for non-exercisers. Another interesting question is whether the boost in aesthetic pleasure is specific to music, or if it generalizes to nonmusical stimuli; for example, after exercise is food tastier, is comedy funnier, is visual art more beautiful or interesting?

In conclusion, results show that exercise leads to increased musical pleasure. Changes in musical enjoyment related to changes in subjective arousal, but not to changes in eye-blink rates or mood. Understanding how the listener's state and circuitry influences musical pleasure can help understand the unique human universal of music, and the profound, yet perplexing, experience of musical pleasure. Exercise's ability to modulate the listener's state and increase musical pleasure could be harnessed to improve wellbeing. For example, depression and low mood are treated with both music (Maratos, Gold, Wang, & Crawford, 2008) and exercise

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(Ströhle, 2009). The current results suggest that combining music and exercise could provide an additive effect to maximize pleasure and therapeutic benefits. Listening to a highly emotional piece of music after exercise could elicit a peak experience. Such peak experiences, although short lived, can transform and reorient people's lives (Keltner & Haidt, 2013). While music and exercise aren't going to supplant established treatments like psychotherapy or pharmacology, they do provide a free, accessible, non-invasive way to increase pleasure. Side effects may include reduced stress, improved cognition, health, and happiness.

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