Supplementary Information for

Bedtime Music, Involuntary Musical Imagery, and Sleep

**(A) Daytime Music**

**(B) Bedtime Routine Music**

Figure S1.*Music preferences during the day and bedtime routine in Study 1.*

Participants reported their preferred music, with frequency of genres separated by daytime preferences (A) and bedtime preferences (B). Prior to illustrating frequency as word clouds, corrections were made for spelling, removal of unnecessary words (e.g., “music” or “listening”), and combination of adjectives that fell into the same category (“all genres,” “any music,” “anything,” etc., were combined to “anything”). Word clouds were generated using WordArt.com.



Figure S2.*Association between music listening/engagement and sleep quality.*

Upper and lower bounds represent 95% confidence intervals. Analyses were adjusted for gender.



Figure S3.*Visual Analogue Scale Ratings before and after music listening in Study 2.*

Table S1. *Sample Characteristics in Study 1.*

Sample characteristics are displayed as mean values with standard deviations in parentheses. Statistical analyses were adjusted for gender.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Infrequent Earworm Control (*n*=46) | Daytime-Only Earworms  (*n*=87) | Sleep-Related Earworms  (*n*=66) | F or χ2  (adjusted p value) |
| Age  (years) | 37.50  (11.70) | 35.99  (11.15) | 34.76  (9.93) | F(2,195)=1.51,  *p*=.22, ηp2=0.02 |
| Gender  (% Female) | 26.09% | 51.72% | 45.45% | χ2(2)=8.16,  *p*=.02, φ=0.20\* |
| Race/Ethnicity  (% Caucasian) | 76.09% | 78.16% | 72.73% | χ2(1)=0.49,  *p*=.49 |
| Chronotype  (Range: 1-4) | 2.41  (1.15) | 2.38  (1.10) | 2.38  (1.08) | F(2,195)=0.04,  *p*=.96, ηp2<.001 |
| Daily Music Listening  (in minutes) | 129.57 (103.13) | 161.44 (145.18) | 162.58  (93.91) | F(2,195)=1.50,  *p*=.23, ηp2=0.02 |
| Bedtime Music Frequency  (Range: 1-7) | 3.74  (2.49) | 3.48  (2.17) | 4.15  (2.19) | F(2,195)=1.60,  *p*=.21, ηp2=0.02 |
| Perceived Impact of Music on Sleep (Range 1-5) | 2.52  (1.11) | 2.62  (1.06) | 2.39  (0.91) | F(2,195)=0.86,  *p*=.43, ηp2=0.01 |
| Music Engagement  (Gold-MSI) | 33.48  (11.70) | 35.61  (11.02) | 40.69  (10.04) | F(2,194)=7.20,  *p*=.001, ηp2=0.07\*\* |
| Negative Valence Earworms (IMIS)a | 17.33  (8.09)a | 15.62  (7.77) | 19.83  (7.98) | F(2,173)=5.20,  *p*=.01, ηp2=0.06\*\* |
| Sleep quality  (PSQI range: 0-21) | 5.21  (2.89) | 5.96  (3.83) | 8.07  (3.18) | F(2,182)=9.89,  *p*<.001, ηp2=0.10\*\*\* |
| Sleepiness  (SSS range: 1-7) | 2.04  (1.37) | 1.97  (1.39) | 2.80  (1.68) | F(2,195)=6.57,  *p*=.002, ηp2=0.06\*\* |
| Insomnia responses to stress (FIRST range: 9-36) | 17.89  (6.34) | 19.37  (7.38) | 24.26  (6.54) | F(2,195)=13.83, *p*<.001, ηp2=0.12\*\*\* |

FIRST=Ford Insomnia Response to Stress Test; Gold-MSI=Goldsmiths Musical Sophistication Index; IMIS =Involuntary Musical Imagery Scale; PSQI=Pittsburgh Sleep Quality Index; SSS=Stanford Sleepiness Scale

aIndividuals who never had an earworm (*n*=24) did not complete these items.

\**p* ≤ .05, \*\**p* < .01, \*\*\**p* < .001.

Table S2. *Frequency of Bedtime Music Listening and Earworm Experiences in Study 1.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Bedtime music listening | Earworms - Trying to fall asleep | Earworms -  Wake in the middle of the night | Earworms – Wake in the morning |
| Never | 43 (21.61%) | 47 (23.62%) | 97 (48.74%) | 65 (32.66%) |
| Rarely (less than once a month) | 44 (22.11%) | 61 (30.65%) | 41 (20.60%) | 42 (21.11%) |
| Once a month | 9 (4.52%) | 17 (8.54%) | 18 (9.05%) | 26 (13.07%) |
| 2-3 times a month | 22 (11.06%) | 30 (15.08%) | 17 (8.54%) | 27 (13.57%) |
| 1-2 times a week | 21 (10.55%) | 27 (13.57%) | 16 (8.04%) | 21 (10.55%) |
| 3-6 times a week | 22 (11.06%) | 11 (5.53%) | 8 (4.02%) | 11 (5.53%) |
| Everyday | 38 (19.10%) | 6 (3.02%) | 2 (1.01%) | 7 (3.52%) |

Data presented as n (%).

Table S3.*Pittsburgh Sleep Quality Index Scores, Bedtimes, and Waketimes Across Earworm Groups in Study 1.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Control Group (Infrequent Earworms) (*n*=46) | Daytime-Only Earworms  (*n*=87) | Sleep-Related Earworms  (*n*=66) | F statistic  (adjusted p value) |
| Bedtime  (hours:min) | 11:12pm  (123.83 min) | 11:14pm (123.81 min) | 10:54pm  (107.78 min) | *F*(2,188)=0.52,  *p*=.59, ηp2=0.01 |
| Risetime  (hours:min) | 6:53am  (125.85 min) | 6:58am  (150.38 min) | 7:02am  (136.24 min) | *F*(2,188)=0.04,  *p*=.96, ηp2<0.001 |
| PSQI Component 1  (Subjective sleep quality) | 0.84  (0.75) | 1.00  (0.69) | 1.27  (0.78) | F(2,182)=4.12, *MSE*=0.53,  *p*=.02, ηp2=0.04 |
| PSQI Component 2  (Sleep latency) | 0.88  (0.85) | 1.07  (0.97) | 1.49  (0.92) | F(2,182)=6.06, *MSE*=0.86,  *p*=.003, ηp2=0.06 |
| PSQI Component 3  (Sleep duration) | 0.79  (0.64) | 0.74  (0.73) | 0.61  (0.72) | F(2,182)=0.87, *MSE*=0.50,  *p*=.42, ηp2=0.01 |
| PSQI Component 4  (Habitual sleep efficiency) | 0.44  (0.88) | 0.49  (0.90) | 0.56  (0.95) | F(2,182)=0.20, *MSE*=0.84,  *p*=.82, ηp2=0.002 |
| PSQI Component 5  (Sleep disturbances) | 1.19  (0.63) | 1.29  (0.80) | 1.75  (0.73) | F(2,182)=8.93, *MSE*=0.55,  *p<*.001, ηp2=0.09 |
| PSQI Component 6  (Use of sleep medication) | 0.49  (0.91) | 0.67  (1.01) | 1.08  (1.10) | F(2,182)=4.82, *MSE*=1.04,  *p*=.01, ηp2=0.05 |
| PSQI Component 7  (Daytime dysfunction) | 0.58  (0.70) | 0.71  (0.83) | 1.31  (0.79) | F(2,182)=13.17, *MSE*=0.63,  *p<*.001, ηp2=0.13 |

Table S4. *Correlational Matrix of Sleep Measures in Study 1.*

*\** indicates *p*<.05, *\*\** indicates *p*<.01, *\*\*\** indicates *p*<.001

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | PSQI global | SSS | FIRST | PSQI comp.1 | PSQI comp.2 | PSQI comp.3 | PSQI comp.4 | PSQI comp.5 | PSQI comp.6 | PSQI comp.7 |
| PSQI global | ---- |  |  |  |  |  |  |  |  |  |
| SSS | .491\*\*\* | ---- |  |  |  |  |  |  |  |  |
| FIRST | .583\*\*\* | .334\*\*\* | ---- |  |  |  |  |  |  |  |
| PSQI comp.1 | .611\*\*\* | .383\*\*\* | .275\*\*\* | ---- |  |  |  |  |  |  |
| PSQI comp.2 | .666\*\*\* | .254\*\*\* | .461\*\*\* | .405\*\*\* | ---- |  |  |  |  |  |
| PSQI comp.3 | .340\*\*\* | .059 | -.024 | .230\*\* | .110 | ---- |  |  |  |  |
| PSQI comp.4 | .564\*\*\* | .235\*\* | .256\*\*\* | .178\* | .207\*\* | .278\*\*\* | ---- |  |  |  |
| PSQI comp.5 | .645\*\*\* | .346\*\*\* | .515\*\*\* | .300\*\*\* | .365\*\*\* | .011 | .223\*\* | ---- |  |  |
| PSQI comp.6 | .626\*\*\* | .331\*\*\* | .412\*\*\* | .216\*\* | .247\*\*\* | -.037 | .203\*\* | .338\*\*\* | ---- |  |
| PSQI comp.7 | .716\*\*\* | .437\*\*\* | .488\*\*\* | .335\*\*\* | .398\*\*\* | .018 | .248\*\*\* | .488\*\*\* | .471\*\*\* | ---- |

Table S5. *Study 1 Linear Regression to Determine Sleep Measure Prediction of Earworm Frequency at Sleep Timepoints.*

**Sleep-Related Earworm Frequency**

**Predictor β Δ*R2* F- or t-test**

Step 1: Control Variables .003 *F*=0.607, *p*=.437

Gender .057 *t*=0.779, *p=*.437

Step 2: Sleep Variables .384 *F*=12.175, *p*<.001\*\*\*

FIRST .302 *t*=3.844, *p<*.001\*\*\*

SSS .116 *t*=1.642, *p=*.102

PSQI Component 1 -.071 *t*=0.990, *p=*.323

PSQI Component 2 -.015 *t*=0.205, *p=*.838

PSQI Component 3 -.097 *t*=1.511, *p=*.133

PSQI Component 4 -.030 *t*=0.464, *p=*.643

PSQI Component 5 .160 *t*=2.164, *p=*.032\*

PSQI Component 6 .097 *t*=1.386, *p=*.168

PSQI Component 7 .188 *t*=2.387, *p=*.018\*

Total R2 = .387

FIRST: Ford Insomnia Response to Stress Test; SSS=Stanford Sleepiness Scale; PSQI: Pittsburgh Sleep Quality Index

\**p* ≤ .05, \*\**p* < .01, \*\*\**p* < .001.

Table S6. *Study 1 Linear Regressions to Determine Sleep Measure Prediction of Music Listening/Engagement (top) and Mediation by Sleep-Related Earworm Frequency (bottom).*

**Gold-MSI Music Listening/Engagement**

**Predictor β Δ*R2* F- or t-test**

Step 1: Control Variables .003 *F*=0.476, *p*=.491

Gender -.051 *t*=0.690, *p=*.491

Step 2: Sleep Variables .146 *F*=3.316, *p*<.001\*\*\*

FIRST .313 *t*=3.374, *p<*.001\*\*\*

SSS .097 *t*=1.168, *p=*.244

PSQI Component 1 -.163 *t*=1.916, *p=*.057

PSQI Component 2 .011 *t*=0.133, *p=*.895

PSQI Component 3 -.072 *t*=0.952, *p=*.342

PSQI Component 4 -.018 *t*=0.226, *p=*.821

PSQI Component 5 .079 *t*=0.905, *p=*.367

PSQI Component 6 -.036 *t*=0.434, *p=*.665

PSQI Component 7 .010 *t*=0.112, *p=*.911

Total R2 = .149

**Gold-MSI Music Listening/Engagement**

**Predictor β Δ*R2* F- or t-test**

Step 1: Control Variables .169 *F*=18.564, *p*<.001\*\*\*

Gender -.077 *t*=1.144, *p=*.25

Sleep-Related Earworm Frequency .409 *t*=6.047, *p*<.001\*\*\*

Step 2: Sleep Variables .047 *F*=1.154, *p*=.328

FIRST .213 *t*=2.287, *p*=.023\*

SSS .061 *t*=0.755, *p=*.451

PSQI Component 1 -.140 *t*=1.705, *p=*.090

PSQI Component 2 .017 *t*=0.202, *p=*.840

PSQI Component 3 -.040 *t*=0.549, *p=*.583

PSQI Component 4 -.008 *t*=0.107, *p=*.915

PSQI Component 5 .026 *t*=0.302, *p=*.763

PSQI Component 6 -.068 *t*=0.850, *p=*.397

PSQI Component 7 -.052 *t*=0.570, *p=*.569

Total R2 = .216

Table S7. *Sample Characteristics for Study 2.*

Sample characteristics are displayed as mean values with standard deviations in parentheses, and separated by music conditions and earworm groups. P values and effect sizes (Cohen’s d or φ) were derived from t-tests (continuous data) and chi square tests (dichotomous data).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Lyrical  Music  (*n*=25) | Instrumental Music  (*n*=23) | Music main effect | No Sleep Earworm (*n*=29) | Yes Sleep Earworm (*n*=19) | Earworm main effect |
| Chronological Age (years) | 20.40  (1.63) | 21.57  (2.59) | *p*=.07  *d*=0.54 | 20.52  (2.10) | 21.63  (2.24) | *p*=.09  *d*=0.52 |
| Gender  (% female) | 84.00% | 56.52% | *p*=.04\*  φ=0.30 | 68.97% | 73.68 | *p*=.73  φ=0.05 |
| Race/Ethnicity  (% Caucasian) | 52.00% | 69.57% | *p*=.21  φ=0.18 | 48.28% | 78.95% | *p*=.03\*  φ=0.31 |
| >3yrs Music Experience | 64.00% | 82.61% | *p*=.15  φ=0.21 | 62.07% | 89.47% | *p*=.04\*  φ=0.30 |
| MEQ chronotype  (total score) | 45.60  (6.96) | 50.41  (8.65) | *p*=.04\*  *d*=0.62 | 47.79  (7.43) | 47.95  (9.18) | *p*=.95  *d*=0.02 |
| Previous week TST (sleep diary, min) | 423.78 (49.01) | 441.79 (47.22) | *p*=.21  *d*=0.37 | 429.18 (48.83) | 437.10 (48.99) | *p*=.59  *d*=0.16 |
| PSQI sleep quality global score | 6.10  (2.28) | 5.50  (2.77) | *p*=.42  *d*=0.24 | 5.48  (1.73) | 6.32  (3.35) | *p*=.27  *d*=0.33 |
| ESS sleepiness score | 10.80  (4.37) | 9.09  (3.10) | *p*=.13  *d*=0.45 | 10.75  (4.12) | 8.89  (3.31) | *p*=.11  *d*=0.49 |
| FIRST stress vulnerability score | 21.72  (4.39) | 18.17  (5.15) | *p*=.01\*  *d*=0.74 | 20.41  (4.66) | 19.42  (5.67) | *p*=.51  *d*=0.20 |
| PSS stress  score | 23.04  (3.72) | 22.04  (3.51) | *p*=.35  *d*=0.28 | 22.79  (3.51) | 22.21  (3.85) | *p*=.59  *d*=0.16 |
| Vocabulary test (of 21) | 14.76  (1.94) | 15.22  (1.73) | *p*=.40  *d*=0.25 | 15.07  (1.89) | 14.84  (1.80) | *p*=.68  *d*=0.12 |
| Raven’s matrices (of 18) | 11.44  (2.20) | 10.59  (2.46) | *p*=.22  *d*=0.37 | 11.46  (2.25) | 10.42  (2.39) | *p*=.14  *d*=0.45 |

MEQ: Morningness-Eveningness Questionnaire; PSQI: Pittsburgh Sleep Quality Index, TST: Total Sleep Time; ESS: Epworth Sleepiness Scale, FIRST: Ford Insomnia Response to Stress Test; PSS: Perceived Stress Scale

\**p* ≤ .05.

Table S8. *Blood Pressure and Heart Rate Data across Conditions and Groups in Study 2, as Acquired from an Omron Automatic Blood Pressure Cuff.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Lyrical Condition (*n*=25) | Instrumental Condition (*n*=23) | No Earworm during Sleep (*n*=29) | Yes Earworm during Sleep (*n*=19) |
| Heart Rate  (pre) | 67.48  (10.38) | 66.17  (8.82) | 66.03  (8.00) | 68.11  (11.73) |
| Heart Rate  (post) | 66.48  (11.56) | 65.65  (10.39) | 65.48  (10.22) | 67.00  (12.11) |
| Systolic Blood Pressure (pre) | 104.52  (12.56) | 111.17 (12.51) | 106.86  (11.95) | 109.00  (14.36) |
| Systolic Blood Pressure (post) | 101.60  (8.66) | 108.70 (11.08) | 103.62  (9.36) | 107.11  (11.81) |
| Diastolic Blood Pressure (pre) | 71.96  (8.40) | 73.09  (7.00) | 72.03  (7.20) | 73.21  (8.56) |
| Diastolic Blood Pressure (post) | 70.64  (7.34) | 72.00  (6.49) | 71.07  (6.77) | 71.63  (7.29) |
| Mean Arterial Pressure (pre) | 124.22  (13.81) | 128.67 (11.52) | 125.47  (12.22) | 127.71  (13.93) |
| Mean Arterial Pressure (post) | 121.44  (10.53) | 126.35 (10.22) | 122.88  (10.34) | 125.18  (11.03) |

Data presented as mean (standard deviation).

Table S9. *Visual Analogue Scale Ratings across Conditions and Groups in Study 2.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Lyrical Condition (*n*=25) | Instrumental Condition (*n*=23) | No Earworm during Sleep (*n*=29) | Yes Earworm during Sleep (*n*=19) |
| Relaxed (pre) | 62.84  (21.33) | 63.70  (18.90) | 65.41  (17.95) | 59.95  (22.88) |
| Relaxed (post) | 72.36  (19.59) | 70.70  (20.67) | 74.45  (17.32) | 67.16  (23.13) |
| Nervous (pre) | 23.84  (19.37) | 23.39  (24.04) | 21.72  (19.28) | 26.53  (24.77) |
| Nervous (post) | 15.76  (15.20) | 16.78  (20.00) | 15.41  (14.81) | 17.53  (21.30) |
| Energetic (pre) | 27.44  (21.90) | 28.78  (18.97) | 27.72  (19.49) | 28.63  (22.12) |
| Energetic (post) | 30.04  (21.08) | 28.96  (22.45) | 30.69  (23.36) | 27.74  (18.84) |
| Sleepy (pre) | 66.84  (19.36) | 65.17  (19.00) | 67.76  (17.16) | 63.42  (21.74) |
| Sleepy (post) | 68.72  (23.18) | 66.17  (18.32) | 67.10  (22.05) | 68.11  (19.34) |
| Stressed (pre) | 32.04  (24.97) | 24.48  (19.95) | 25.03  (20.00) | 33.58  (26.20) |
| Stressed (post) | 25.76  (21.15) | 18.30  (16.23) | 22.21  (19.60) | 22.16  (18.91) |

Data presented as mean (standard deviation).

Table S10. *Polysomnographic Data across Music Conditions and Earworm Groups in Study 2.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Popular Lyrical  Music Condition (*n*=25) | Instrumental Music Condition (*n*=23) | No Earworm during Sleep (*n*=29) | Yes Earworm during Sleep (*n*=19) |
| Total Sleep Time (min) | 507.42  (24.46) | 497.74  (25.97) | 499.66  (24.72) | 507.54  (26.35) |
| Sleep Efficiency (%) | 94.31%  (2.97) | 91.88%  (4.75) | 94.28%  (3.64) | 91.42%  (4.17) |
| Sleep Onset Latency (min) | 10.50  (8.82) | 15.89  (13.35) | 10.00  (8.37) | 17.79  (13.90) |
| Wake After Sleep Onset (min) | 21.32  (13.50) | 28.31  (18.82) | 21.26  (14.07) | 29.87  (18.29) |
| Number of Awakenings | 22.76  (10.54) | 22.61  (9.37) | 19.69  (7.50) | 27.26  (11.46) |
| N1  (min) | 22.86  (13.63) | 24.58  (15.98) | 18.77  (9.80) | 31.19  (17.73) |
| N2  (min) | 296.88  (28.85) | 288.97  (28.14) | 290.75  (29.82) | 296.66  (26.73) |
| N3  (min) | 86.94  (26.03) | 76.09  (16.72) | 86.47  (20.84) | 74.53  (23.59) |
| REM  (min) | 100.64  (25.35) | 107.97  (26.53) | 103.59  (25.86) | 105.01  (26.67) |

Data presented as mean (standard deviation).

*Table S11. Quantitative EEG Analysis across Music Conditions and Sleep-Related Earworm Groups.*

Analyses were conducted during N3 epochs, averaged across frontal channels, and constrained to hypothesized sleep EEG correlates of memory consolidation.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Popular Lyrical  Music Condition (*n*=25) | Instrumental Music Condition (*n*=23) | Statistic |
| Slow oscillation power (in μV2) | 29.28 (10.37) | 29.54 (12.81) | *F*(1, 42) = 0.001,  *p* = .972, ηp2 < 0.01 |
| Theta power  (in μV2) | 3.90 (1.20) | 4.50 (2.07) | *F*(1, 42) = 1.50,  *p* = .228, ηp2 = 0.03 |
| Spindle Density (per minute) | 2.56 (0.57) | 2.36 (0.51) | *F*(1, 42) = 0.04,  *p* = .845, ηp2 < 0.01 |
|  | No Earworm during Sleep (*n*=29) | Yes Earworm during Sleep (*n*=19) | Statistic |
| Slow oscillation power (in μV2) | 26.12 (6.52) | 34.40 (15.30) | *F*(1, 46) = 6.69,  *p* = .013, ηp2 = 0.13 |
| Theta power  (in μV2) | 3.83 (1.12) | 4.73 (2.21) | *F*(1, 46) = 3.49,  *p* = .068, ηp2 = 0.07 |
| Spindle Density (per minute) | 2.45 (0.53) | 2.49 (0.58) | *F*(1, 45) = 0.05,  *p* = .825, ηp2 < 0.01 |

Data presented as mean (standard deviation).