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# Modulating musical reward sensitivity up and down with transcranial magnetic stimulation

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## **Supplementary Methods**

### *Stimuli selection*

Each participant was instructed to provide five excerpts (with a duration of 45 seconds) of music that elicited intensely pleasant emotional responses. During the three sessions participants listened to these five songs. In addition, on each session, they also listened to ten additional experimenter-selected songs that varied from session to session. For this purpose three lists of ten song excerpts (also with duration of 45 seconds) were selected. In order to ensure that the lists of songs were comparable across sessions, we selected thirty songs from ten different bands (three songs for each band). Thus, on each session participant listened to one song of each band (ten in total). With this procedure we aimed to homogenize the three lists of songs.

In the experimenter-selected list we aimed to select songs that were slightly familiar (to ensure pleasant reactions) but not easily recognizable for the participants, as we wanted them to purchase these songs during the experiment. In order to meet this criterion, we selected thirty songs that were, in the last two years, in the top 40 in Canada (<http://top40-charts.com/>) but without reaching the top 5 (See Table S1). Then, we generated three list of 10 songs matched in their top 40 position. Additionally, using a Spotify application (<http://static.echonest.com/SortYourMusic/>), we also matched them according to different features computed by Spotify's algorithms, such as bpm, danceability, energy, valence, loudness, popularity and acoustic (see Table S2).

### *Music Task*

On each session, participants listened to their five favorite songs (self-selected songs) and ten other songs (experimenter-selected songs). The order of presentation of both groups

of songs were counterbalanced across participants. Additionally the order of presentation within each group of songs was randomized. While listening to music, the participants had to rate, in real-time, the degree of pleasure they were experiencing by pressing one of four different buttons on a keyboard (1=neutral, 2=low pleasure, 3=high pleasure, 4=chill). The participants had to hold down the button as long as they were experiencing the corresponding degree of pleasure. At the end of each excerpt, the participants were asked to rate the familiarity (from 1 = unfamiliar to 4 = I have it in my PC, mp3, Spotify list, etc) as well as the emotional valence (from 1=sad to 9=happy) and arousal (from 1=not at all arousing to 4=highly arousing) they felt in response to the musical excerpt. The songs from the experimenter selection that the participants reported to already have in their musical list were discarded from the analysis ( $M = .31$ ,  $SD = .64$ ).

Additionally, the participants could purchase the music selected for the experiment (not their own favorite songs) with their own money in an auction paradigm, as an indication that they wanted to hear it again. Each participant was given a budget of \$18 (\$6 per session), and could keep the amount that was not spent. This way, they were spending their own money on music. For each song, participants could indicate whether they were willing to pay \$0, \$0.99, \$1.29 or \$2. At the end of each session, three excerpts were randomly selected. If their bets were the same or higher than the real price of the songs (which was randomly assigned at the beginning of the experiment, changing from \$0.99, \$1.29 to \$2, and thus, unknown for the participants), they would get a legal copy of the song at the end of the experiment. In that case, the amount of money they were willing to pay was discounted from the initial budget. In contrast, if their bet was lower than the real price, they would not get the song, but keep their budget. At the end of the experiment participants received an Amazon gift card with the value of the remaining budget.

The two measures (real-time ratings and monetary bids) are sensitive to different processes. While real-time rating may be a measure of their 'liking', the amount of money spent may be considered a measure of 'wanting'.

#### *Electrodermal activity (EDA)*

EDA was recorded through ProComp Infiniti units (Thought Technology Ltd, Montreal, QC) during task performance. The electrodes were attached to the forefinger and the middle finger of the left hand and placed in the first phalange. Baseline physiological data was recorded during three minutes of rest prior to the task. EDA associated to music listening was analyzed by computing the proportion of change of EDA during music listening compared to the baseline period.

Additionally, fEMG activity was acquired by using two Ag–AgCl skin electrodes placed on the corrugator supercilii muscle and a ground electrode on the forehead. Spontaneous eye blinks were also measured using two Ag–AgCl electrodes placed above and below the left eye and a ground electrode placed on the forehead. This data is not reported in the current study.

#### *Theta Burst Stimulation (TBS)*

TBS was applied using a Magstim Super Rapid stimulator during the three sessions. In the first session, active motor threshold (aMT) was determined.

In order to estimate aMT, the left primary motor cortex was stimulated in a single pulse protocol to elicit motor-evoked potentials (MEPs) from the first dorsal interosseous (FDI). Using surface Ag/AgCl disk electrodes, electromyographic activity from the contralateral FDI was recorded. In order to find the MT hot-spot, we started with 50% of the highest maximum stimulator output, which was sufficient in most participants to

evoke MEPs; otherwise, intensity was increased in 5% steps. An optimal spot was found by moving the coil in 0.5-1 cm increments on the scalp, starting from approximately 5 cm lateral from the vertex of the head, until the spot with the highest MEP was found. aMT was defined as the minimum intensity that produced a visible MEP ( $>200 \mu\text{V}$ ) in 50% of 10 trials during isometric contraction of the target muscle (Rossini et al., 1994). This threshold was used to set the intensity of the stimulation (80 % of aMT).

TBS was delivered using a TBS pattern consisting of bursts of 3 pulses at 50 Hz repeated at 5 Hz. For iTBS, a 2 s train of TBS was repeated every 10 s for a total of 190 s (600 pulses) (Huang et al. 2005). In the cTBS paradigm, a 40 s train of uninterrupted TBS was given (600 pulses) (Huang et al. 2005). The sham stimulation was delivered with the coil positioned at a perpendicular angle to the target area using either the iTBS or cTBS protocol, in a counterbalanced manner, across the subjects.

The coordinates selected for the left DLPFC ( $x = -40$ ,  $y = 32$ , and  $z = 30$ ) were the same than the study of Strafella and colleagues (2001), which showed for the first time a release of striatal dopamine following excitatory TMS. The Talairach coordinates were converted into MNI coordinates and then into subject's native MNI space using the reverse native-to-MNI transformation from SPM. A real-time optically tracked frameless stereotaxic system (Brainsight <sup>TM</sup> Frameless, Rogue Research Inc., Montreal, Canada) was used to guide the coil over the subject's scalp. An infrared camera for online subject tracking and coil positioning (Polaris Spectra, NDI) was used. The coil was held in a fixed position by a mechanical arm (which provided flexible positioning and rotation of the coil in multiple directions) over the target area and was oriented so that the induced electric current flowed in a posterior-anterior direction.

## Supplementary Tables

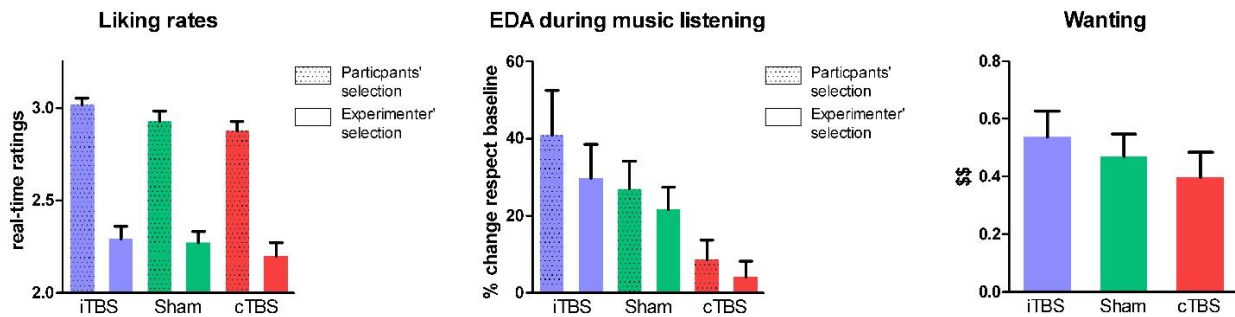
| Artist        | Set 1                              | Set 2                     | Set 3                   |
|---------------|------------------------------------|---------------------------|-------------------------|
| MAGIC!        | Don't Kill the Magic               | Let Your Hair Down        | No Way No               |
| Ariana Grande | Focus                              | Santa Tell Me             | One Last Time           |
| Selena Gomez  | I Want You To Know                 | Same Old Love             | Slow Down               |
| One Direction | Steal My Girl                      | Infinity                  | Night Changes           |
| Lana Del Rey  | West Coast                         | High By The Beach         | Summertime Sadness      |
| Keith Urban   | John Cougar, John Deere, John 3_16 | Cop Car                   | Shame                   |
| Jason Derulo  | Wiggle                             | Trumpets                  | Marry Me                |
| Hedley        | Pocket Full Of Dreams              | Heaven In Our Headlights  | Crazy For You           |
| Flo Rida      | GDFR                               | I Don't Like It I Love It | My House                |
| Coldplay      | Magic                              | Midnight                  | Adventure Of A Lifetime |

**Supplementary table 1:** Songs selected for the present study.

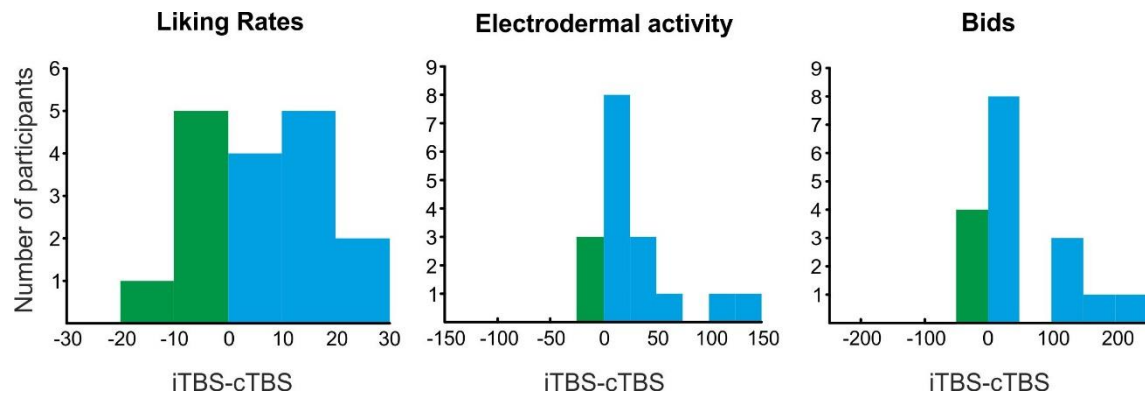
|                 | Set 1        | Set 2        | Set 3        | ANOVA ( <i>p</i> value) |
|-----------------|--------------|--------------|--------------|-------------------------|
| Top 40 position | 18,3 (10,6)  | 18,4 (11,3)  | 17,8 (10,5)  | .98                     |
| BPM             | 126,4 (30,4) | 115,3 (18,9) | 117,4 (29,3) | .41                     |
| Energy          | 69 (12,3)    | 69,7 (11,6)  | 72,2 (14,6)  | .49                     |
| Danceability    | 59,8 (10,4)  | 65,2 (6,2)   | 62,1 (9,9)   | .51                     |
| Loudness        | -6 (2,7)     | -5,5 (1,3)   | -6,2 (1,8)   | .36                     |
| Valence         | 46,4 (23,5)  | 47,1 (24,7)  | 54 (22,3)    | .54                     |
| Acoustic        | 12,3 (22,6)  | 13,6 (25,7)  | 9,5 (11,7)   | .63                     |
| Popularity      | 72,1 (11,2)  | 69,5 (17,3)  | 68,4 (10,2)  | .97                     |

**Supplementary table 2:** Mean and standard deviation for each musical set for the different features matched across sets. The *p* values resulting from the ANOVA analysis comparing the different sets are also reported.

## Supplementary Figures



**Supplementary Figure 1.** (A) Liking rates, (B) Electrodermal activity during music listening and (C) the money spent to buy the music following intermittent theta burst (iTBS), sham and continuous theta burst stimulation (cTBS). In the case of Liking rates and EDA data area shown for both experimenter-selected and participant-selected music.



**Supplementary Figure 2.** Distribution of the difference between iTBS vs cTBS in liking rates, electrodermal activity and the amount of money participants were willing to pay. Positive numbers indicate a change in the predicted direction between iTBS and cTBS (blue bars); negative numbers indicate a change in the opposite direction (green bars). Note that in all cases the distribution is shifted to the right (positive values), with most of the participants showing an increase after iTBS with respect cTBS (blue bars).