

Rewarding Properties of Music Increases Savings in Sensorimotor Adaptation

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Abstract

Learning to adapt motor outputs in response to changes in sensory feedback, or sensorimotor adaptation, is essential to rehabilitation following injury or disease. There are two learning mechanisms in sensorimotor adaptation: savings and anterograde interference. It has been proposed that savings is subserved by reinforcement learning (Huang et al., 2011) processes while anterograde interference is subserved by use-dependent plasticity (Leow et al., 2014) processes. Both learning processes are dopamine sensitive. Music modulates dopamine dependent reward responses. This study investigates the effect of rewarding properties of music on savings and anterograde interference in two experiments. Seventy-five right-handed healthy participants completed a sensorimotor adaptation task which assessed both savings and anterograde interference. In Experiment 1, participants were randomly assigned to one of three conditions (1) listen to music that induced a positive mood state (2) listen to music that induced a negative mood state, or (3) silence. Music was individually selected for each participant based on individual ratings. To examine whether music acts upon savings and anterograde interference by modulating reward mechanisms, we ran Experiment 2, which was identical to Experiment 1, except that visual rewards were presented when movements were within 10 degrees of the target. It was hypothesized that music should act upon savings more so than anterograde interference.

Keywords: sensorimotor adaptation, savings, anterograde interference, music, reinforcement, retention

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Rewarding Properties of Music Increases Savings in Motor Adaptation

Motor learning occurs on a regular basis in everyday circumstances and is necessary for movement rehabilitation. An example of motor learning is learning to play a sport such as tennis. At first, a person new to tennis would make many errors in trying to hit the tennis ball consistently over the net. However, eventually they would be able to hit the tennis ball fairly consistently over the net through trial, error, and practice (Krakauer, 2009; Huang & Krakauer, 2009). To study motor learning, many laboratories use sensorimotor adaptation tasks. These tasks involve learning by adapting to movements in response to changes in sensory feedback. For example, a sensorimotor adaptation task might require participants to adjust to a computer mouse that moves a cursor faster than expected (Bastian, 2008). At initial learning, a person would have difficulty using this computer mouse and make many errors. But eventually they would adapt their movements to take into account the unexpected cursor feedback (Bastian, 2008; Krakauer, 2009). After this adaptation period, and the person switches back in using the previous slower mouse-cursor feedback, they will initially make large errors again because of the persistence of the adapted fast mouse-cursor movement (Bastian, 2008). However, eventually they will return in making their original movements that they used for the slower mouse-cursor feedback; before the exposure of the fast mouse-cursor feedback (Bastian, 2008). Some clinical applications of sensorimotor adaptation include the use of prism goggles in hemi neglect patients to promote attention to the neglected side (Rossetti et al, 1998), and the use of limb perturbation through the use of a robot to normalize reaching movements in stroke survivors (Reinkensmeyer, 2004; Patton, Stoykov, Kovic, & Mussa-Ivaldi, 2006; Krakauer, 2006).

Sensorimotor adaptation tasks examine how participants adapt movements to perturbations in sensory feedback as participants make reaching movements from a start point to

a target point. Two types of sensorimotor adaptation tasks are commonly used: visuomotor adaptation and force-field adaptation. In visuomotor adaptation, participants reach as direct vision of their arm is obscured from sight and visual feedback of their arm position is provided on a computer screen. On-screen visual feedback of their movements are perturbed, typically by rotating visual feedback relative to the start point. In force-field adaptation, a deflecting force (i.e., force field) is applied on the arm (Huang, Haith, Mazzoni, & Krakauer, 2011). Participants hold the handle of a robotic arm and make reaching movements to visual targets displayed on a screen (Shadmehr & Mussa-Ivaldi, 1994). A perturbation (a force-field in this case) is then applied, acting on the moving arm causing participants to make skewed movements). Before the application of the force-field, participants are easily able to make smooth and straight movements. Through practice, participants adapt to the force-field (i.e. perturbation) and again make smooth and straight movements. However, when the force-field is removed, participants would make skewed movements once again. In both visuomotor adaptation and force-field adaptation, participants correct for the errors made due to the perturbation, to return their performance levels to pre-perturbation levels.

Model-based and model-free learning

Error reduction in sensorimotor adaptation is generally thought to occur by updating an internal model (Huang et al, 2011; Leow, Rugey, Loftus, & Hammond, 2013). Our central nervous system is able to alter arm movements in response to a perturbation (a force field or rotation of the visual feedback), to form a new map between the arm state and the muscle forces the arms uses in response to these perturbations (Krakauer, 2006). People exhibit retention (i.e., positive or negative transfer) of sensorimotor adaptation learning; learning to adapt to one perturbation can transfer to learning to adapt to other perturbations (Krakauer, 2006). Haith, and

Krakauer (2013) suggest two different learning mechanisms to account for both initial error reduction in sensorimotor adaptation and the retention of sensorimotor adaptation. The first learning mechanism, known as *model-based learning*, uses internal models of the input-output relationship between the motor command and its sensory consequences. When a perturbation results in a discrepancy between the motor command and the predicted sensory consequences of this motor command (i.e., a sensory prediction error), the internal model is updated to generate a motor command to reduce the sensory prediction error. The second mechanism is thought to occur without relying on updating an internal (hence termed *model-free learning*). Model-free learning has been proposed to occur via reinforcement learning mechanisms - remembering and repeating actions that led to success or the best outcome. Model-free learning was proposed in order to account for the persistent effects of initial learning on subsequent relearning after the motor output is returned to pre-adapted, original state. A model-based account would predict that the rate of relearning after returning motor output to the pre-adapted state would be the same as the rate of initial learning. The persistent effect of initial learning can be evident in a phenomenon known as *savings*, in which initial learning enhances subsequent adaptation to a similar perturbation, such that relearning that given perturbation is faster than initial learning (Huang et al, 2011). Savings has been proposed to result from faster recollection of a reinforced action rather than a re-expression of a previously learned internal model (Huang et al, 2011). Therefore savings relies on a model-free learning process, specifically reinforcement learning (Huang et al, 2011). Another phenomenon demonstrating the persistence of initial learning is anterograde interference (Sing & Smith, 2010; Krakauer, 2011).

Reinforcement learning involves repeatedly pairing an adapted movement with a rewarding outcome (e.g., hitting the target) that reinforces that movement such that there would be a bias toward reselecting that movement. On the other hand, use-dependent plasticity is where repetition of a particular movement (i.e., independently of a reward associated with the adaptation) would bias subsequent movements toward the repeated movement (Krakauer, 2011; Haith & Krakauer, 2013). Huang et al. (2011) suggested that savings reflects the recall of a motor memory formed through the model-free learning process that uses reinforcement mechanisms of actions. They also predicted that anterograde interference should occur when initial learning hinders subsequent adaptation to an opposing perturbation or movement (Huang et al, 2011). Anterograde interference is likely to occur when repetition of a particular action leads future movements to be biased towards that action and when learning a subsequent movement has an opposing perturbation (Huang et al, 2011). In experiment 3 of Huang et al's (2011) study, they used an A1-B-A2 reaching paradigm, where participants were instructed to sequentially learn to adapt to a rotation in the first block A1, followed by a second, opposite rotation in the second block B. Crucially, by clever manipulation of the target direction, the adapted movement solution for A1 and B were the same. They found that despite the opposite rotations at A1 and B, savings was evident from A1 to B. Therefore, Huang et al. (2011) propose that savings occurs via reinforcement—the adapted movement solution for A1 was reinforced by task success and movement repetition, and retrieved when learning B. The proposal that savings and anterograde interference involves reinforcement mechanisms is supported by previous findings of impaired savings and anterograde interference in Parkinson's disease patients, who show deficient dopamine function and consequently impaired reinforcement learning (Marinelli et al, 2009; Bédard & Sanes, 2011; Leow, Loftus, & Hammond, 2012; Leow et al, 2013).

Rewarding properties of music

Music is a strong modulator of dopamine reward responses. Salimpoor, Benovoy, Larcher, Dagher, and Zatorre (2011) investigated the rewarding properties of music and found that music elicited dopamine-dependent reward responses. Emotional responses to music were associated with distinct patterns of brain activity. Dopamine was released from the ventral striatum when high emotional pleasure was experienced in response to music. Many of the neural regions associated with listening to music that evoke positive emotion are also activated in response to dopamine based rewards (Blood & Zatorre, 2001; Salimpoor et al, 2011). Through the use of PET scan, intensely pleasurable emotional responses to music, referred to as “chills,” were found to activate the ventral striatum and anterior cingulate, brain regions typically thought to be involved in pleasure and reward (Blood & Zatorre, 2001). Regions that are activated by other primary rewarding stimuli such as food, sex, and drugs of abuse were also found activated when listening to pleasurable music (Blood & Zatorre, 2001).

Gold, Frank, Bogert, and Brattico (2013) examined whether musical pleasure facilitates reinforcement learning through dopamine elicitation. They had subjects listen to either one or both of a neutral piece of music and pleasurable music, which they chose from an experimental-compiled database, when performing the probabilistic selection (PS) task. Subjects would have to choose the higher probabilistic change of reward between three different image pairs of Japanese Hiragana characters displayed on a screen in an allotted time. Each image pair would have different reward certainties (0% to 100%). Gold et al. (2013) found that musical pleasure affected task performance and that pieces of music that were noted as pleasurable accelerated reaction times. A recent unpublished data from our lab has investigated the effects of music on sensorimotor adaptation (Waclawik, 2014). The findings suggested that listening to music while

adapting to a 30 degree rotation of visual feedback, elicits more persistence of the adapted movements after the rotation of visual feedback is removed. Pleasurable music seemed to increase persistence of learning more so than when listening to no music (Waclawik, 2014). As music is a strong modulator of reward mechanisms, we suggest that the rewarding properties of music altered reinforcement mechanisms, thus increasing the retention of learning. In this vein, the rewarding properties of music may also act upon savings and anterograde interference by affecting reinforcement mechanisms in sensorimotor adaptation.

Study aims and hypotheses

It is unclear whether savings and anterograde interference occur through the use of the same model-free process, or through different model-free processes: reinforcement learning and use-dependent plasticity. To further examine the rewarding properties of music on reinforcement learning and use-dependent plasticity processes on savings and anterograde interference, two experiments were conducted. The first experiment design will be based upon the experiment in the study conducted by Huang et al. (2011), with the addition of music. Participants will either be listening to one pleasurable (positive and rewarding) or less-pleasurable (negative and less rewarding) piece of music where arousal is the same. We also included a silent control group, who did not listen to music during learning. Given that savings is mediated by reinforcement learning (Huang et al, 2011), music-induced facilitation of reinforcement learning during the task would be expected to result in an increase in savings. Furthermore, given that anterograde interference is mediated by use-dependent plasticity, music should have less of an effect (Huang et al, 2011). The second experiment was conducted to further examine the effects of music on savings and its reliance on a reward. Two visual rewards will be given in addition to music in the

second experiment. The same paradigm will be used in the second experiment as the first experiment.

Experiment 1

Method

Participants

Forty-five undergraduate students in the first year introductory psychology course at Western University were recruited in exchange for a 1.0 course credit ($M_{\text{age}} = 18.57$ years, $SD = 1.05$). All participants were right-handed, had normal to corrected-to-normal vision, had no hearing or neurological deficits, and were the age of 18 years or older. The study was approved by the Research Ethics Board of Western University.

Materials

Participants sat in a chair at a desk, on which there was a digitizing tablet (Intuos 5 Touch Large Pen Tablet; width of 48.77 cm, length of 31.75 cm, height of 1.27 cm; 260.1 cm² of active area; resolution 0.05 mm) underneath a black stand (width of 53.34 cm, length of 38.10 cm, height of 25.40 cm). Participants made movements on the tablet using a digitizing pen (length of 15.7 cm long, diameter of 1.5 cm, weight of 17 g). On top of the stand was a laptop which displayed the pen's position on the tablet with a radius of 5 pixels. A movement of 3.5 cm on the tablet produced a 7 cm movement on the screen. Displayed on the monitor were a start circle (8 pixels) and a target (23 pixels). The target alternated between two possible equidistant locations (7.5 cm from the start point); either at the 1:00pm clock position or at the 2:30pm clock position in reference to the start point. Custom software written in LabVIEW 12.0 recorded the data. Participants used headphones (Sennheiser HD 280 Pro) to listen to music throughout the task.

The musical stimuli were selected from a database of music clips created in 2011- 2013 that had been previously rated on arousal and mood (Waclawik, 2014).

Procedure

Participants were randomly assigned to either the positive, negative music condition, or the silent condition. They were first given a music ratings task, in which they were asked to rate a number of positive (music that elicited a positive state or were the most rewarding) or negative (music that elicited a negative state or the least rewarding) songs. Participants in the silent condition rated only two songs, which were both taken from the original Bock (2010) study. Each song required a rating on familiarity, enjoyment, arousal level of the music, mood of the music, and induced mood (the participant's mood after listening to the music), on a scale of 1-10 (1 = not at all or low and 10 = very much or high). Participants were encouraged to use the full scale and to listen to as much of each song as they felt was necessary in order to accurately complete the scale. Based on individual ratings, the experimenter then selected the song that was rated highest on induced mood (for positive or most rewarding) or lowest (for negative or least rewarding) in induced mood to play for the rest of the experiment. Those randomly assigned to the silent group performed the task in silence.

At the start of the sensorimotor adaptation task, a series of instructions appeared on-screen and were read to the participant by the experimenter. The instructions informed the participant that their task was to “move the cursor from the start point to a target in a single straight movement, as quickly and accurately as possible, and to make movements at the elbow rather than the wrist to encourage straight movements.” Finally, the participants were told that: “From time to time, the feedback of your movement (i.e., the pen trace shown on the laptop) will be altered. Your job is to alter your movement in response to this alteration in feedback”. The

feedback was altered only during the adaptation phases; when the rotations were applied to the targets.

The adaptation task consisted of 30 practice trials (15 per target location), followed by 400 adaptation trials. In the initial learning block A1, 160 trials were designated for target 1 (with a 30° counterclockwise rotation applied), followed by 80 no rotation trials for target 1. In the relearning block B, participants completed 80 trials for target 2 (with a 30° clockwise rotation). Crucially, by separating the target locations for initial learning block A1 and relearning block B, the adapted movement solution was the same for initial learning A1 and subsequent relearning block B. This paradigm resulted in savings from A1 to B in a previous study (Huang et al., 2011) despite opposite rotations. Finally, to examine anterograde interference, participants completed a final 80 trials for target 2 with a 30° counterclockwise rotation in block A2. Thus the visual feedback of the participants' movement (i.e. the pen trace shown on the laptop screen) was rotated by 30° counterclockwise or clockwise. Finally, there were 26 wash-out trials at the end of the 400 adaptation trials in which normal visual feedback was restored, giving a total of 426 trials. The visual feedback, which was a line trace of the participants' pen movement, was real-time, online feedback, and remained on-screen for 1s after the trial had ended. After the adaptation task, participants once again completed the rating scales for the one song they had been listening to throughout the experiment. Those in the silent condition rated both original songs they rated previously once again. The entire procedure took approximately 60 minutes.

Experiment 2

Method

Experiment 2 used the same apparatus, musical stimuli, and procedure as Experiment 1. The only difference was that, two visual rewards were added during the rotation adaptation

phases when participants made a reaching movement which was at peak velocity within 10° of an ideal movement to the target, or directly hit the target. These visual rewards were two colorful images containing the words “Well Done” and “Bang!”. The two images were presented on either side of the screen (one on the left, the other on the right) at about the same height as the start point.

Participants

Thirty undergraduate students in the first year introductory psychology course at Western University were recruited in exchange for a 1.0 course credit ($M_{\text{age}} = 18.43$ years, $SD = 0.68$). All participants were right-handed, had normal to corrected-to-normal vision, had no hearing or neurological deficits, and were the age of 18 years or older. The study was approved by the Research Ethics Board of Western University.

Experiment 1 & 2 Data Analysis

Cartesian XY coordinates of the pen movements were recorded by the computer program, and used to calculate the directional error at peak velocity (the distance between an accurate straight movement from the start point and the participants’ real-time movement). Directional errors greater than 60° were excluded from analysis because directional error greater than twice the rotation suggest irregularities in the trials. This resulted in exclusion of 0.384% of all data. Directional errors were scored as negative or positive when the on-screen movement trajectory was counterclockwise or clockwise to an ideal movement respectively. For each trial, directional errors were converted into percentages for statistical analyses (see below) (Krakauer, Pine, Ghilardi, & Ghez, 2000).

$$100 * \left(1 - \frac{DirErrVpk}{30^\circ}\right)$$

Trial by trial percent adaptation was then averaged across bins. The three blocks (A1, B, and A2) each consisted of four bins. One bin consisted of a number of trials. The sizes of bins were optimized to characterize the error reduction phase (i.e. bin 1 and bin 2) and the plateau phase (i.e. bin 3 and bin 4). Bin sizes between blocks remained consistent.

Savings was quantified by subtracting block A1 mean percent adaptation from block B mean percent adaptation for all four bins. Anterograde interference was quantified by subtracting B mean percent adaptation from A2 mean percent adaptation for all four bins. Three-way repeated ANOVAs were used to evaluate block-to-block changes in percent adaptation within each group; directional error as the dependent variable, bin (12 bins) as a within-subjects factor, and music condition (positive, negative, or silent) and reward condition (no reward or reward) as between-subjects factors. Effect sizes were evaluated using η^2 where 0.02~ small, 0.13~ medium, and 0.26~ large. Block-to-block changes in percent adaptation were reported as means \pm standard errors of the mean. Where Mauchley's test of sphericity was violated, the Greenhouse-Geisser adjustment was used.

Results

Figure 1 displays the average directional errors across all 426 trials for each music group in all the rotation adaptation phases (black lines). Figure 2 displays the average directional errors across all 426 trials for each music group in all the rotation adaptation phases (black lines) when visual rewards were added. In the rotation phases in both figures in A1, directional errors approximated the size of the rotation in the first trial, and decreased across trials. Analyses revealed a near significant interaction of bin \times music \times reward $F(3.73, 128.6) = 2.52, p = 0.048, \eta^2 = 0.068$. There was no significant main effect of music \times reward, $F(2, 69) = 0.98, p = 0.382, \eta^2 = 0.028$. The significant music \times visual reward interaction suggested that the effect of music

depended on the presence or absence of visual reward. This was investigated via follow-up ANOVAs, described as follows.

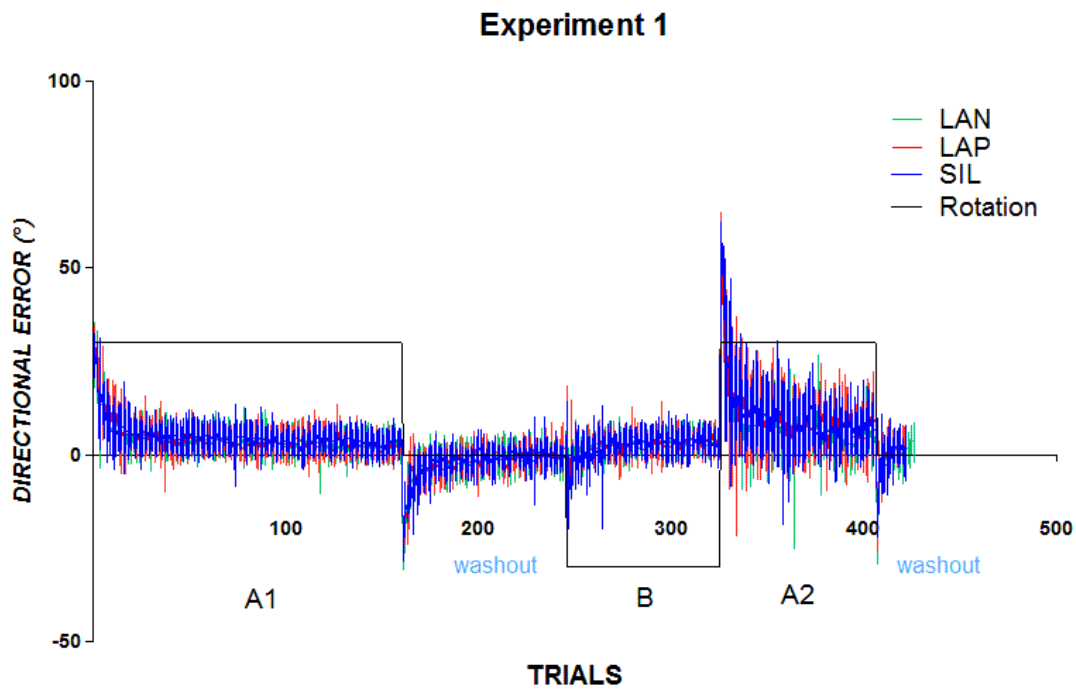


Figure 1. Experiment 1 (No Reward). Average directional errors across trials for participants listening to negative music, positive music, or no music. Directional errors decrease across trials.

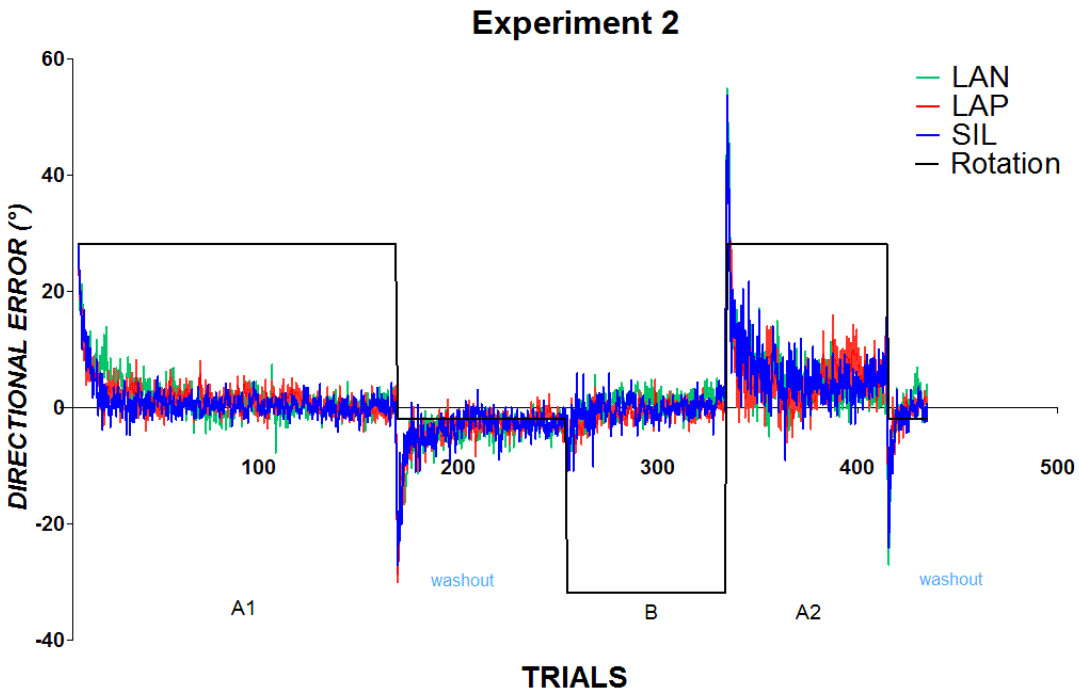


Figure 2. Experiment 2 (Reward). Average directional errors across trials for participants listening to negative music, positive music, or no music, with a visual reward feedback given throughout the entire task. Directional errors decrease across trials.

Savings

To determine whether the effects of visual rewards on savings and anterograde interference depend on music presence, 3-way ANOVA's with within-subjects factors bin and between-subjects factors reward (no reward, reward) and music (LAP, LAN, silence) were conducted.

A near significant interaction of bin x music x reward was found, $F(3.88, 133.9) = 2.51$, $p = 0.046$, $\eta^2 = 0.068$. However, no significant main effect of music x reward, $F(2, 69) = 0.94$, $p = 0.396$, $\eta^2 = 0.026$ was found. To evaluate how music affected savings with and without visual rewards, two bin x music ANOVAs were run separately for the No Reward (Experiment 1) and

Reward (Experiment 2) groups.¹ For the No Reward group, a significant interaction of bin x music was found, $F(4.06, 85.2) = 3.02, p = 0.022, \eta^2 = 0.126$. No significant main effect of music was found, $F(2, 42) = 0.002, p = 0.998, \eta^2 = 0$ (see **Figure 3**). For the Reward group, no significant interaction of bin x music was found, $F(3.38, 45.6) = 1.34, p = 0.273, \eta^2 = 0.090$. No significant main effect of music was found, $F(2, 27) = 1.82, p = 0.181, \eta^2 = 0.119$ (see **Figure 4**). Hence, music only affected savings when visual reward was not concurrently present (Experiment 1), and not when visual reward was concurrently present (Experiment 2).

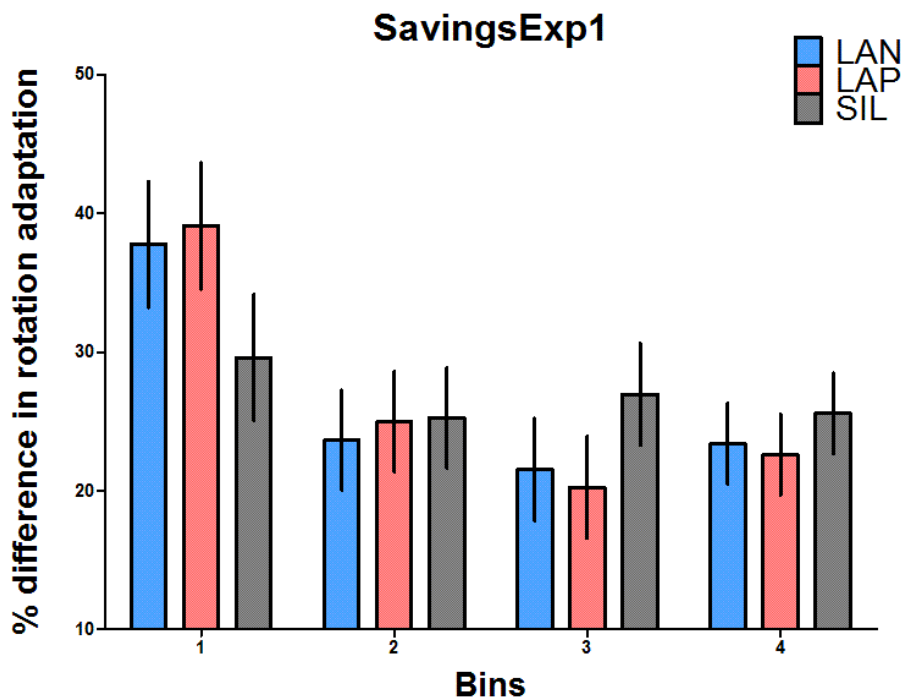


Figure 3. Mean percent difference in rotation adaptation of block A1 and block B of Experiment 1 (No Reward) for the three music groups, LAN, LAP, and SIL across four bins. Larger values indicate greater savings. Error bars show one standard error of the mean.

¹ It is also possible to run bin x reward ANOVAs separately for each music condition (LAP, LAN, silence). This analysis was reported in the Appendix.

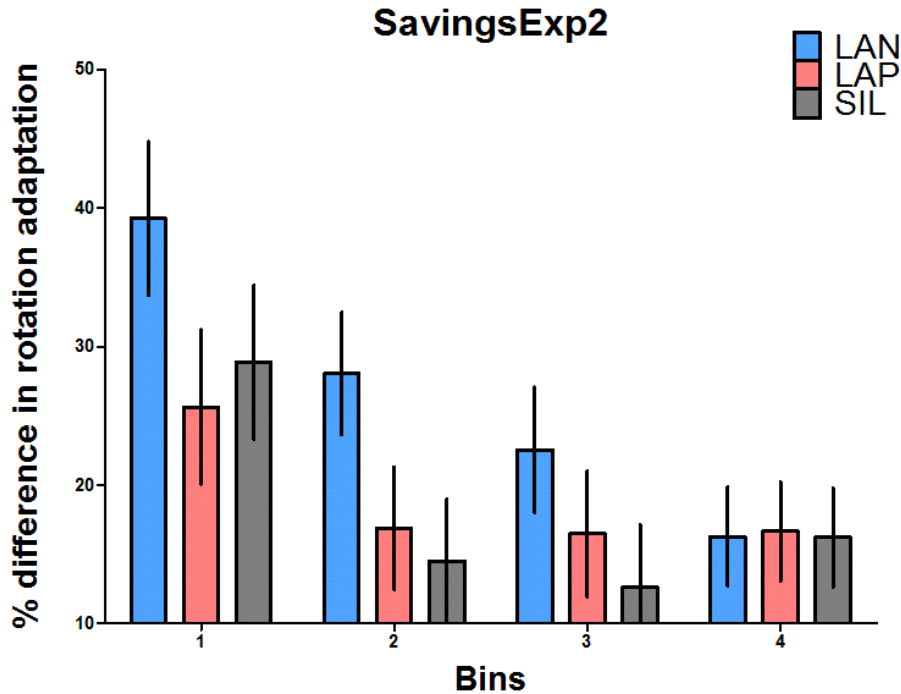


Figure 4. Mean percent difference in rotation adaptation of block A1 and block B of Experiment 2 (Reward) for the three music groups, LAN, LAP, and SIL across four bins. Larger values indicate greater savings. Error bars show one standard error of the mean.

Anterograde Interference

ANOVAs with within-subjects factors bin and between-subjects factors reward (no reward, reward) and music (LAP, LAN, silence) were run for anterograde interference. No significant interaction of bin x music x reward was found, $F(3.41, 117.7) = 0.67, p \geq 0.589, \eta^2 = 0.019$. Moreover, no significant main effect of music x reward was found, $F(2, 69) = 0.26, p = 0.773, \eta^2 = 0.007$ (**Figure 5 & Figure 6**). Music alone did not seem to affect anterograde interference. The addition of visual rewards to music also did not affect anterograde interference.

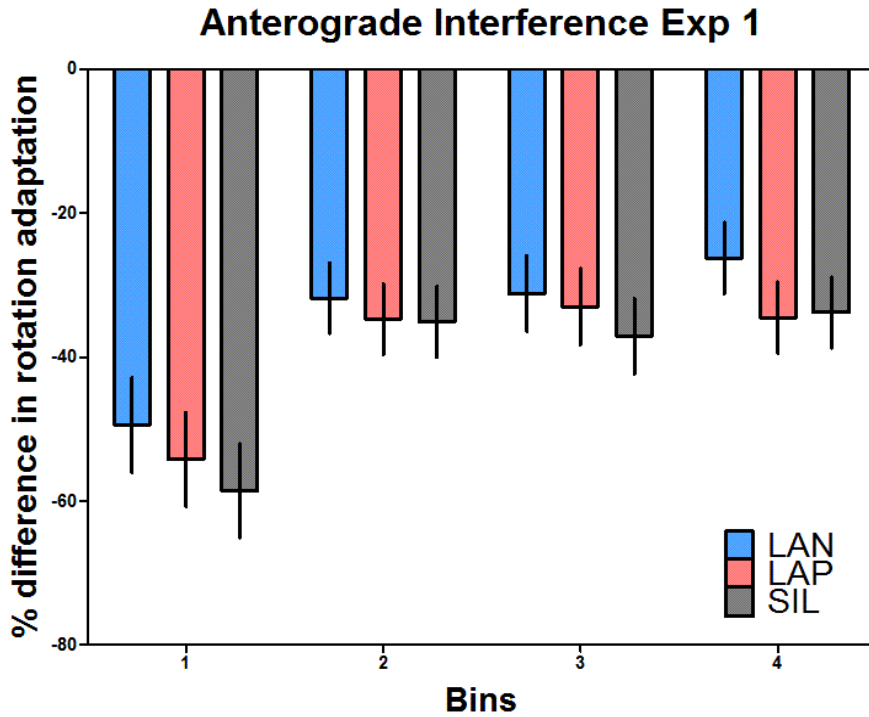


Figure 5. Mean percent difference in rotation adaptation of block B and block A2 of Experiment 1 (No Reward) for the three music groups, LAN, LAP, and SIL across four bins. Larger values indicated greater anterograde interference effects. Error bars show one standard error of the mean.

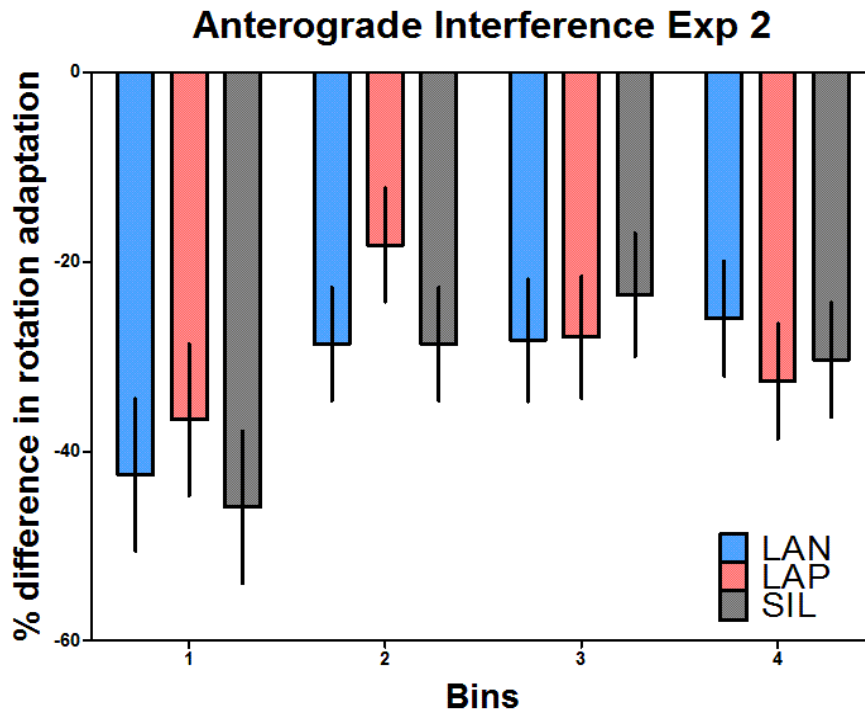


Figure 6. Mean percent difference in rotation adaptation of block B and block A2 of Experiment 2 (Reward) for the three music groups, LAN, LAP, and SIL across four bins. Larger values indicated greater anterograde interference effects. Error bars show one standard error of the mean.

Discussion

The purpose of the current study was to examine how the rewarding properties of music via inducing positive or negative mood states, affect retention of visuomotor adaptation, quantified via savings and anterograde interference. Experiment 1 aimed to replicate Experiment 3 of the study by Huang et al (2011) with the addition of music. Experiment 1 showed that music seemed to have an effect on savings. This was consistent with our hypothesis that based on previous evidence that reinforcement affects retention (Huang et al, 2011) and music can elicit dopamine reward responses (Salimpoor et al, 2011), music would increase savings by acting upon reward mechanisms (Gold et al, 2013). Experiment 2 aimed to further examine the rewarding properties of music by incorporating two visual rewards. The results were surprising

in that with the addition of visual rewards or a binary reward with music, there was a decrease in savings. In both Experiment 1 (no visual reward) and Experiment 2 (visual reward), music had no significant effect on anterograde interference.

In the current study, without the visual rewards (Experiment 1), the group who listened to music that elicited a positive state (more rewarding music) showed more savings than the group who did not listen to music. In Experiment 2, in the presence of visual rewards, music failed to increase savings, but rather the effects of music were overridden by the visual rewards for the positive music and silent groups. One interpretation is that the addition of visual rewards may have changed the rate of initial learning compared to when there was no visual reward. Contrary to a study by Shmeulof et al. (2012), where they found that the addition of success-based reinforcement (i.e. visual rewards) contributes to longer-term retention of the adapted solution movement, the present study found the opposite to be true. The addition of visual rewards when participants successfully hit the target while listening to pleasurable music, elicited a decrease in retention rather than an increase (see **Appendix Figure 8 & Figure 9**). Our measures of savings may have been inflated. As was statistically found, there was a significant interaction between bin, music and reward condition group in A1. In order to determine if the rate of initial learning was different between the experiments due to the addition of visual rewards, examination of the four bins within A1 should be conducted.

Another interpretation for the results found in Experiment 2 where the effects of music were overridden by the visual rewards for the positive music and silent groups, is that the perturbation evokes a negative reward prediction error. A negative reward prediction error occurs when the participant expects to receive reward (successfully hitting the target) but does not receive the reward due to the perturbation. This interpretation is consistent with recent

findings of faster error reduction at initial learning and greater savings at relearning when pennies were removed from participants when they failed to hit the target accurately (Galea, Mallia, Rothwell, & Diedrichsen, 2015). By accentuating this negative reward prediction error with punishment (i.e. removal of pennies), initial learning was faster. Moreover, subsequent learning was also faster, as evident in greater savings. Re-acquiring the target after error reduction is thought to be rewarding (Huang et al, 2011), and accentuating this reward signal with visual and auditory rewards when participants moved close to the target appears effective in modulating adaptation performance (Izawa, & Shadmehr, 2011; Shmuelof et al, 2012). Hence, typical adaptation tasks might be sub-served by both punishment and reward mechanisms.

Interestingly, the negative (less rewarding) music group (LAN), showed no difference in savings with or without visual rewards (see **Appendix Figure 7**). Visual reward manipulation in Experiment 2 seems to be less effective with the LAN group compared to the LAP group. Less pleasurable music or ‘negative’ music (LAN group) may make individuals less susceptible to visual reward manipulation. Thus savings does not change when visual rewards are added with less pleasurable music (see **Appendix Figure 8**). One interpretation is that the less pleasurable music may be inhibiting the effect of visual rewards-- as participants are already in a negative state due to the less pleasurable music, adding visual rewards to this may not have an effect (Galea et al, 2015).

Furthermore, contrary to our findings with savings, music and visual reward did not significantly affect anterograde interference. One interpretation of this finding is that our study was not optimized to examine anterograde interference. The paradigm used in this study was different to that of the one used in Huang et al. (2011), such that to investigate anterograde interference, an opposite rotation of that in B, was applied in A2. Our study design might not

have been optimized to examine the effects of reinforcement on anterograde interference, as there might have been savings effects from A1 to B. A design that solely examines anterograde interference might be more sensitive to the effects of reward--- thus far, no studies have directly examined the influence of reinforcement on anterograde interference. An alternative interpretation is that anterograde interference might not be subserved by reinforcement learning. A recent study has suggested that anterograde interference might be subserved by use-dependent plasticity, which is the phenomenon where repetition of a movement (i.e., independently of a reward associated with the adaptation) biases subsequent movements (Haith & Krakauer, 2013). Leow, Hammond, and Rugey (2014) examined the contribution of use-dependent plasticity to anterograde interference during movement repetition by stimulating the motor cortex (MI) with anodal transcranial direct current stimulation (tDCS). Using the same A1-B-A2 paradigm as in Huang et al. (2011) study, they found there was an increase in anterograde interference with extended movement repetition, but not with limited movement repetition. On the contrary, there was no increase in savings. Leow et al. (2014) suggest that use-dependent plasticity from movement repetition does not contribute to savings but rather contribute to anterograde interference. Therefore a follow-up study optimizing for examination of anterograde interference would provide further support in the interpretation that anterograde interference is subserved by use-dependent plasticity than reinforcement learning.

Limitations and Future Directions

The current study was limited in experimental design, more specifically, when music was being played through the experiment. By playing music throughout the entire experiment, we gave participants a contextual cue of being in the same state throughout performing the task. Isolating when the music should be played during the experiment would help identify the effects

of music more so; to see if music actually helps retention of the adapted movements and therefore contribute to savings. Playing the music during the block A1 (the first 160 trials) only, would have fixed this limitation. It would help identify whether the effects of music is carried-over in block B (when the opposite rotation is applied to a new target), and therefore retention of the adapted movement was kept.

Another limitation to the study is that we did not consider individual differences in regards to musical experience and background of the participants. Gold et al. (2013) found that the musical background of an individual contribute to the extent at which music acts upon reinforcement learning. In Experiment 2 the value of music as a reward may have decreased once the visual rewards were added. Visual rewards alone may be less effective than manipulating primary rewards such as food. The addition of a questionnaire asking participants for their musical experience and background knowledge would help to determine the extent at which the pieces of music are rewarding on an individual basis.

Furthermore, since this study focused on rewards, a follow-up study incorporating punishment and reward, would be helpful in examining the results found in this study. Galea et al. (2015) found that punishment led to faster initial learning compared to when individuals were given a reward. Reward helped with memory retention. Therefore in a follow-up study, adding punishment will help further examine the rewarding properties of music. Further research is also needed on examining the mechanics of anterograde interference as there is still few literature examining whether anterograde interference is subserved by use-dependent plasticity alone or by reinforcement and use-dependent plasticity As relatively few studies focus on anterograde interference and the mechanisms behind it (Cothros, Kohler, Dickie, Mirsattari, & Gribble,

2006; Cothros, Wong, & Gribble, 2009; Sing & Smith, 2010), future studies should focus more on this aspect of motor learning.

Conclusions

The current study validates previous evidence that even with opposing rotations applied to a different target location, savings is evident (Huang et al, 2011). Based on the current and available literature, this study provides new evidence and examination of the rewarding properties of music on savings in motor learning, but in addition anterograde interference. It provides further evidence that music has similar effects on motor learning retention as standard reinforcement paradigms (Gold et al, 2013). The current study found that music alone can contribute to greater savings but not anterograde interference. However with the addition of visual rewards, the effects of music were overridden. As sensorimotor adaptation is essential to many types of rehabilitation, music may be able to contribute more greatly in these rehabilitation and therapeutic purposes. Further research on factors that may help to improve long-term adaptation and retention for rehabilitation would be beneficial to create optimal treatment programs. Future studies should examine the long-term benefits of music on sensorimotor adaptation and retention.

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Appendix A

Savings

LAN.

To evaluate the effect of reward separately for each music condition (LAP, LAN, Silence), we ran separate bin x reward ANOVAs for each music condition (LAP, LAN, Silence). For LAN, no significant interaction of bin x reward was found, $F(1.94, 44.6) = 1.38$, $p \geq 0.261$, $\eta^2 = 0.057$. Moreover, no significant main effect of reward was found, $F(1, 23) = 0.0$, $p = 0.995$, $\eta^2 = 0.00$. Music alone did not seem to affect savings and the addition of visual rewards to music also did not affect savings (see **Figure 7**).

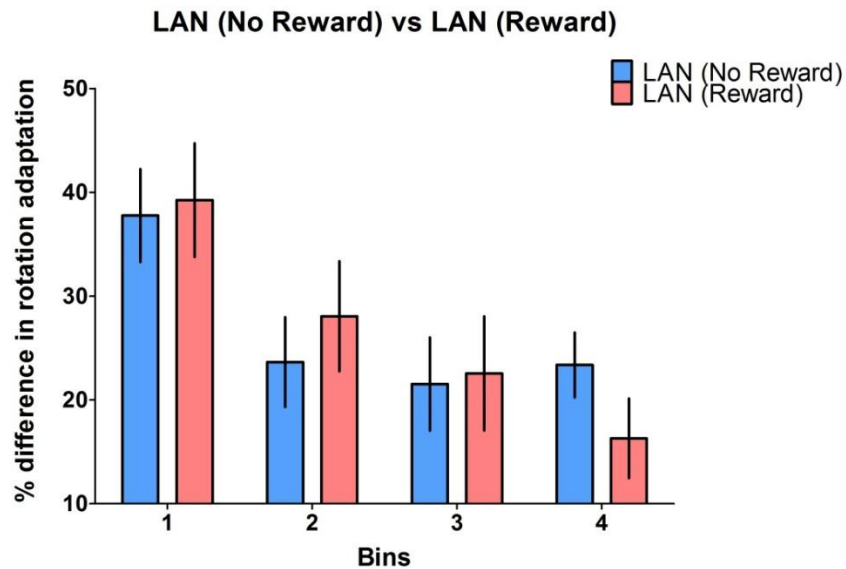


Figure 7. Mean percent difference in rotation adaptation of block A1 and block B of music group LAN for the two reward groups No Reward (Experiment 1) and Reward (Experiment 2) across four bins. Larger values indicate greater savings. Error bars show one standard error of the mean.

LAP.

No significant interaction of bin x reward was found, $F(2.11, 48.5) = 1.84, p \geq 0.168, \eta^2 = 0.074$. Moreover, no significant main effect of reward was found, $F(1, 23) = 2.56, p = 0.123, \eta^2 = 0.100$. Music alone did not seem to affect savings and the addition of visual rewards to music also did not affect savings (see **Figure 8**)

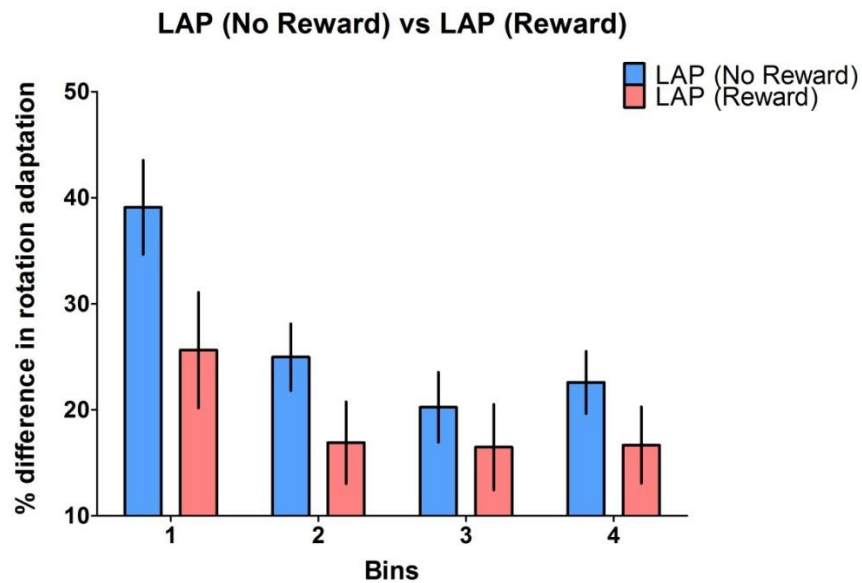


Figure 8. Mean percent difference in rotation adaptation of block A1 and block B of music group LAP for the two reward groups No Reward (Experiment 1) and Reward (Experiment 2) across four bins. Larger values indicate greater savings. Error bars show one standard error of the mean.

SIL.

No significant interaction of bin x reward was found, $F(1.74, 39.96) = 2.33, p \geq 0.117, \eta^2 = 0.092$. Moreover, no significant main effect of reward was found, $F(1, 23) = 3.88, p =$

0.061, $\eta^2 = 0.144$. Music alone did not seem to affect savings and the addition of visual rewards to music also did not affect savings (see **Figure 9**).

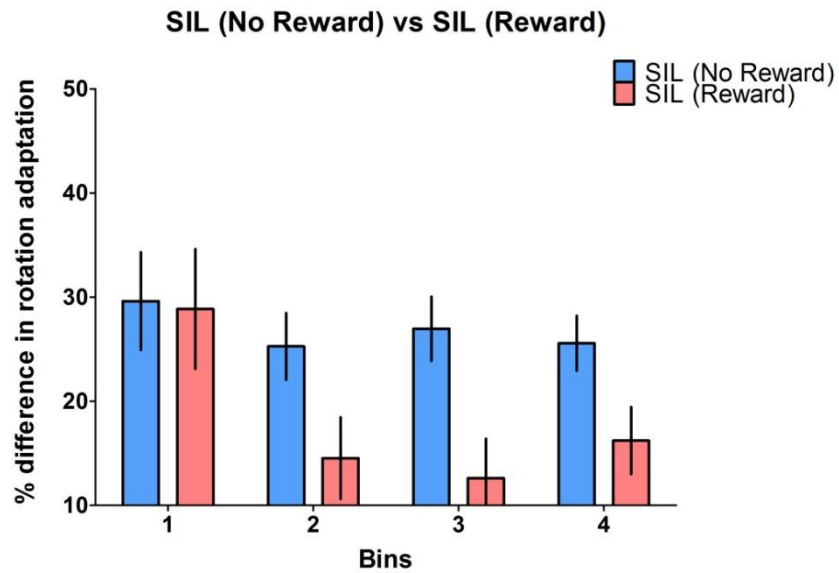


Figure 9. Mean percent difference in rotation adaptation of block A1 and block B of SIL for the two reward groups No Reward (Experiment 1) and Reward (Experiment 2) across four bins. Larger values indicate greater savings. Error bars show one standard error of the mean.