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CNS Abstract 2012

**Title:** Multi-Voxel Pattern Analysis of Brain States After Compassion Training Predicts Charitable Donations

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## Long Abstract

### Introduction

Compassion is the feeling of caring for and wanting to help others who are suffering, and is a key determinant of altruistic behavior. Compassion may be trained through meditation and is thought to result in greater real-world altruistic behavior (Lutz, Brefczynski-Lewis, Johnstone & Davidson, 2008). Recent work demonstrates that short-term compassion training increases helping behavior (Leiberg, Klimecki & Singer, 2011), but the neural mechanisms underlying such effects remain unknown. In this study, we investigate whether short-term compassion training alters brain functioning, and whether post-training brain activity predicts subsequent altruistic behavior.

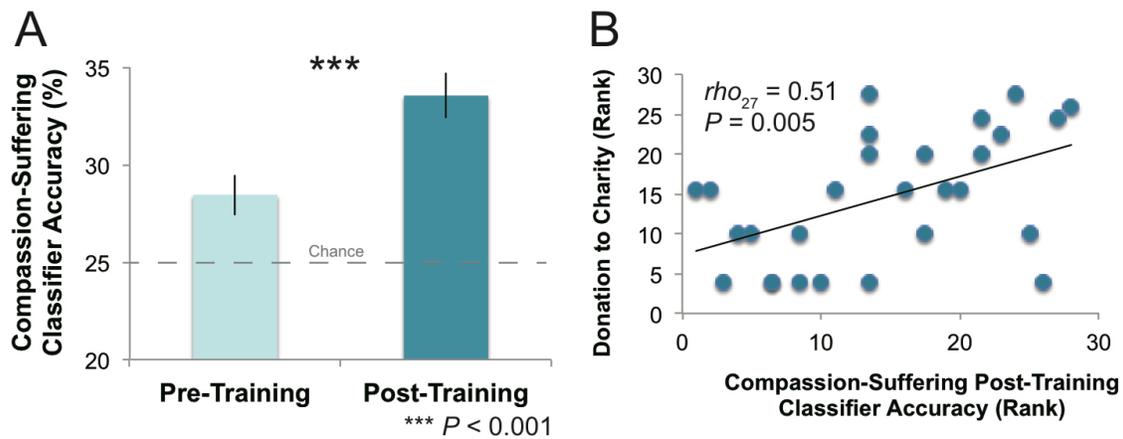
### Methods

Participants were randomized to either two weeks of compassion meditation (N=28) or cognitive reappraisal (N=28) training and practiced 30 min/day via the Internet. Brain activity was measured with fMRI in pre and post-training sessions in which participants were instructed to voluntarily generate compassion for (Compassion) or simply attend to (Attend) pictures depicting human suffering (Suffering) or non-suffering (Neutral) for 12s. The reappraisal group was instructed to use Reappraisal (Ochsner & Gross, 2005) or Attend to the same images. In each session, multi-voxel pattern analysis (MVPA; see Norman et al., 2006 for a review) was used to assess the stability of brain activity patterns elicited during each condition. To assess altruistic behavior after training, participants were given the opportunity to donate personal earnings to a charity of their choice.

For MVPA analyses, a feature selection ANOVA was applied to select voxels that varied between the 4 conditions ( $P < 0.05$ ). A pattern classifier was trained separately for each participant for 6 TRs of each trial (TR=2s) from each condition using penalized logistic regression with L2 regularization and a penalty parameter of 50 (Duda, Hart, & Stork, 2001). Compassion training-related changes in brain state reliability were computed with paired *t*-tests comparing post-training to pre-training classifier accuracy in each condition. To assess the relationships between post-training accuracy and behavior, average post-training classifier accuracy was correlated with donation amount using Spearman's *rho*.

## Results

After training, the pattern classifier decoded brain states more accurately in Compassion-Suffering trials (**Fig. 1A**; Pre: 28.5% [chance: 25%]; Post: 33.5%;  $t_{167}=3.77$ ,  $P<0.001$ ). Critically, the post-training reliability of an individual's Compassion-Suffering brain patterns was predictive of the amount of money the individual donated to charity (**Fig. 1B**;  $\rho_{27}=0.51$ ,  $P=0.005$ ). This pattern was not found in the other conditions; Compassion-Neutral and Attend-Suffering trials were not identified more accurately after training ( $P$ 's $>0.49$ ), and although reliability increased in Attend-Neutral trials ( $t_{167}=4.33$ ,  $P<0.001$ ), this post-training accuracy did not predict donations ( $\rho_{27}=-0.009$ ,  $P=0.97$ ). Demonstrating the specificity of compassion training's impact on altruistic behavior, the relationship between post-training Reappraisal-Suffering classification and donations was not significant ( $P=0.82$ ).



**Figure 1.** (A) Compassion training increases classifier accuracy in Compassion-Suffering trials. (B) Post-training Compassion-Suffering accuracy predicts charitable donations.

## Conclusions

These findings indicate that brain patterns elicited while generating compassion towards images of suffering become more reliable after compassion training. Furthermore, the greater the reliability was after training, the more money participants subsequently donated to charity. These results suggest that brain states made systematically more reliable by compassion training can increase real-world altruistic behavior.

## References

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