



Universidad Autónoma
de Madrid

Biblos-e Archivo
Repositorio Institucional UAM

Repositorio Institucional de la Universidad Autónoma de Madrid

<https://repositorio.uam.es>

Esta es la **versión de autor** del artículo publicado en:
This is an **author produced version** of a paper published in:

Personality and Individual Differences 74 (2015): 165 – 170

DOI: <https://doi.org/10.1016/j.paid.2014.10.014>

Copyright: © 2014 Elsevier Ltd. All rights reserved. This manuscript version is made available under the CC-BY- NC-ND 4.0 licence <http://creativecommons.org/licenses/by-nc-nd/4.0/>

El acceso a la versión del editor puede requerir la suscripción del recurso
Access to the published version may require subscription

**Adaptive working memory training reveals a negligible effect of emotional stimuli
over cognitive processing**

Francisco J. Román¹, María J. García-Rubio¹, Jesús Privado², Dominique Kessel¹, Sara
López-Martín¹, Kenia Martínez^{1, 3}, Pei-Chun Shih¹, Manuel Tapia¹,
Juan Manuel Serrano¹, Luis Carretié¹, Roberto Colom^{1*}

(1) Universidad Autónoma de Madrid, 28049, Madrid (Spain).

(2) Universidad Complutense de Madrid, 28223, Madrid (Spain).

(3) Hospital Gregorio Marañón, Madrid, 28007 (Spain)

** Corresponding author:*

Roberto Colom

Universidad Autónoma de Madrid

28049 Madrid (Spain)

Voice: 91 497 41 14

Email: roberto.colom@uam.es

ABSTRACT

Here we analyze how performance differences in an adaptive cognitive training regime based on the n-back task interact with emotional stimuli (scenes and faces) varying in their valence (negative, positive, and neutral). One hundred and three participants completed four training sessions across two weeks showing remarkable improvements from time to time. Results revealed no differences between faces and scenes regarding accuracy levels across increased complexity levels. However, reaction times (RTs) were sensitive to emotional conditions to some extent. Observed faster RTs to negative faces (disgust) were consistent with the negativity bias phenomenon, but this effect vanished for the highest levels of processing complexity. It is suggested that emotional information contents fail to interact with cognition when there are no cognitive resources left after the primary task is addressed.

KEYWORDS: n-back task, adaptive training, faces, scenes, emotion

INTRODUCTION

Cognitive training is capturing substantial scientific and media interest. Elderly people (e.g., Fandakova, Shing, & Lindenberger, 2012; Zelinski, 2009), ADHD patients (e.g., Beck, Hanson, Puffenberger, Benninger & Benninger, 2005; Klingberg et al., 2005) or schizophrenic individuals (e.g., Twamley, Jeste & Bellack, 2003; Subramaniam et al., 2012) are usual target populations. The training programs are based on different cognitive functions, but given its theoretical relevance (Ackerman, Beier & Boyle, 2005; Colom, Abad, Quiroga, Shih & Flores-Mendoza, 2008; Cowan et al., 2005; Martínez et al., 2011), working memory (WM) is frequently addressed. Two key issues have been discussed with respect to WM training. Firstly, are improvements in WM related with increased scores in far-transfer measures such as fluid intelligence tests? (Colom et al., 2010, 2013; Chooi & Thompson, 2012; Jaeggi et al., 2008, 2010a, 2011; Redick et al., 2013; Shipstead, Redick & Engle, 2012). Secondly, are these WM changes associated with variations in brain structure and function? (e.g., Buschkuhl, Hernandez-Garcia, Jaeggi, Bernard & Jonides, 2014; Jaušovec & Jaušovec, 2012; Jolles et al., 2010; McKendrick, Ayaz, Olmstead & Parasuraman, 2014; Olesen, Westerberg & Klingberg, 2004; Takeuchi et al., 2011). However, little attention has been devoted to the nature (neutral or emotional) of the information to be processed.

The n-back task has been used for designing WM training programs (Colom et al., 2013, Jaeggi et al. 2008, 2011; Stephenson & Halpern, 2013). However, to our knowledge, there are not studies addressing the interaction between cognitive performance observed in these training programs and emotional stimuli. For filling this gap here we study two types of stimuli, scenes and faces (Coan & Allen, 2007), because (a) they are important in evolutionary terms (Carretié et al., 2013), and (b) they are

known to interact with cognitive requirements (e.g., Eastwood, Smilek & Merikle, 2003). Scenes are associated with affective reactions, such as phobias, and they have a direct explicit affective meaning (Carretié et al., 2013). They correlate with psychophysiological responses providing validity to subjectively reported emotion induction (Lang & Bradley, 2007), and with neural activation (e. g. Britton et al., 2006; Carretié et al., 2004, 2013; Olofsson, Nordin, Sequeira, & Polich, 2008). Faces are important in social interactions (Frith, 2007). Psychophysiological and brain responses to faces have been extensively studied (e.g. Achaibou, Portois, Schwartz, & Vuilleumier, 2008; Aguado et al; 2012; 2013; Britton et al., 2006). Furthermore, scenes and faces allow using negative, neutral and positive emotional valences.

Here we investigate if there are behavioral differences between negative, neutral and positive stimuli (faces and scenes) comprised in an adaptive cognitive training based on the single n-back task. The interaction between emotion and memory has been investigated within several frameworks: episodic memory (e.g., Pillemer, Goldsmith, Panter, & White, 1988), long-term storage (e.g., Buchanan & Adolphs, 2003; Charles, Mather, & Carstensen, 2003) or working memory (e.g., Gray, 2001; Gray, Braver, & Raichle, 2002) but findings are far from consistent when the goal of the study is the nature of the stimuli (Gotoh, 2008; Holmes et al., 2009; Kensinger and Corkins, 2003; Levens & Gotlib, 2010, 2012, Lindström & Bohlin, 2011).

The theoretical framework for the present study is based on previous evidence showing that individual differences in working memory can be attributed to capacity limitations for keeping a reliable mental representation of the relevant information (Colom et al., 2005, 2006, 2013, Martínez et al., 2011). Therefore, we predict that emotions evoked by scenes and faces will interact with cognitive performance in the

completed adaptive training program for the simplest processing levels. However, emotion will lose their evocative role at increased levels of cognitive complexity.

METHOD

Participants

Participants were recruited from the Faculty of Psychology ($N = 76$, 72.19%) and the Faculty of Computer Science ($N = 27$, 27.81%) at Universidad Autónoma de Madrid ($N = 103$, 61.20% were females). Their mean age was 19.86 ($SD = 3.85$). Participants were randomly assigned to two groups: Face training ($N = 51$) and Scene training ($N = 52$ with 20.02). This study followed the Declaration of Helsinki.

Procedure and Stimuli

The training regime consisted of four sessions completed across two weeks. In each session, participants performed the adaptive n-back task for approx. 30 minutes within individual cabins and under strict supervision. Participants were instructed to respond -as accurately and quickly as possible- each time the current stimulus was identical to that presented n positions back in the sequence, pressing the space bar for targets only. In the first session, participants started at level 1 (1-back) for each emotional condition. The difficulty level increased or decreased according to their performance at each emotional block. N-back level was increased when participants had less than three omission or commission errors. N-back level was reduced when participants committed more than five omission and commission errors.

For successive sessions, each participant began at the level achieved in the previous session for all stimuli. For example, if a participant achieved level 4 for negative stimuli, level 3 for positive stimuli, and level 2 for neutral stimuli in session one, then session two begins in level 4 for negative stimuli, level 3 for positive stimuli, and level 2 for neutral stimuli.

Faces and scenes (negative, positive and neutral) were employed for all sessions. Specifically, each session included 12 blocks (4 blocks per emotional condition: neutral, negative and positive) with 20 + n stimuli for each block. All stimuli were displayed at a rate of 3s (stimulus length, 500 ms. interstimulus interval, 2500 ms; see Figure 1 for faces and Figure 2 for scenes). The order of emotional conditions was randomized for each participant within sessions. The four blocks for each emotional condition were successively administered. For example, the sequence in one session for a participant in the face group was: blocks 1-4: neutral faces, blocks 5- 8: positive faces, and blocks 9-12: negative faces.

PLEASE INSERT FIGURE 1 and 2 ABOUT HERE

In the training group using faces, happy expressions were employed as positive stimuli, since expressions of positive valence other than happiness are problematic with respect to recognition rate (Tracy & Robins, 2008). Moreover, the expression used as negative stimulus was also single: disgust faces were selected, since it is better recognized (in terms of both reaction times and accuracy) than other negative expressions, such as fear or sadness (Tracy & Robins, 2008). Neutral, negative and positive emotional faces were selected from the FACES database (Ebner et al., 2010).

In the training group using scenes, stimuli were selected from the International Affective Picture System (IAPS) (Lang et al., 2005) and from EmoMadrid (<http://www.uam.es/carretie/EmoMadrid.htm>). All emotional scenes were chosen according to valence and arousal average assessments provided by these databases (See Figure 1 for an example of the n-back task with emotional stimuli).

Analyses

First, we obtained the percentage of improvement for each condition according to this formula (Chooi & Thompson, 2012).

$$\% \text{Improvement} = \frac{\text{Avg.Highest Training score} - \text{Avg.First Training score}}{\text{Avg.Highest score}} \times 100 \quad [1]$$

A mixed ANOVA (3 x 2) was computed to check if improvement across training sessions was different for faces and scenes. Emotion (Negative, Neutral and Positive) was a within-subject factor and Training (Faces and Scenes) was a between-subject factor.

Second, mixed ANOVAs (2 x 4 x 3) --Training (Faces and Scenes), Sessions (S1, S2, S3, S4) and Emotion (Negative, Positive and Neutral)—were computed for the n-back level achieved in each session and for the reaction times (RTs) of correct trials only. Emotion and Sessions were within-subjects factors and Training was between-subjects factor. The Greenhouse-Geisser correction was applied when the sphericity assumption was violated for all analyses. Finally, post-hoc analyses were computed using the Bonferroni correction.

RESULTS

1. Improvement

The percentage of improvement for face training was 52.08% for negative, 50.71% for neutral and 53.18% for positive stimuli. For scene training the percentage was of 55.89% for negative, 54.71% for neutral and 55.08% for positive stimuli. Therefore, values were very similar for all emotional conditions in both types of training. The results of the mixed ANOVA (3 x 2; Emotion x Training) failed to show significant differences ($p > .05$ for all effects).

2. Performance (n-back level and reaction times)

Table 1 shows results for each n-back level and their respective RTs. Only significant results for both analyses will be described.

PLEASE INSERT TABLE 1 ABOUT HERE

2. 1. N-back level

The only significant result regarding n-back level was the main effect of Session $F(3,303) = 316.328; p < .001; \eta^2 = .758$ (Figure 3). Post hoc analyses showed that performance increased across sessions for scenes (Figure 3a) and faces (Figure 3b). Thus, performance rates were different from session to session ($p < .001$) and equal for both types of training. Results show that performance increases linearly to the same extent for both instances ($S4 > S3 > S2 > S1$).

PLEASE INSERT FIGURE 3 ABOUT HERE

2.2. Reaction Times (RTs)

Figure 4 depicts RTs for Scenes (Figure 4a) and for Faces (Figure 4b). These were the significant results: (a) Main effect of Session and its interaction with Training, $F(3,303) = 316.328; p < .001; \eta^2 = .758$; , $F(3,612) = 6.008; p = .002; \eta^2 = .056$. Post-hoc analyses showed slower RTs in S1 for Scene training than for Face training ($p < .001$) but no differences were observed between both types of training during S2, S3 and S4. (b) Main effect of Emotion and its interaction with Training [$F(2,202) = 12.825; p < .001; \eta^2 = .113$ and $F(2,408) = 5.545; p = .007; \eta^2 = .052$ respectively]. Post-hoc analyses showed that RTs for Negative stimuli were faster during Face training than during Scene training in S2 and S3 ($p < .001$), while Positive and Neutral

stimuli were processed faster in Scene training but only in S1 ($p < .001$). (c) Interaction between Emotion and Session, $F(6,606) = 2.245$; $p = .038$; $\eta^2 = .022$. Post-hoc analyses showed that RTs for Negative Faces were faster for S1, S2 and S3 than for Neutral and Positive Faces ($p < .001$). No significant differences were found for Scenes.

PLEASE INSERT FIGURE 4 ABOUT HERE

In summary, RTs were equal for scenes irrespective of emotion. However, responses to Negative Faces were faster in S1, S2 and S3 than for Neutral and Positive Faces. Finally, when comparing both types of training (Faces and Scenes), responses to Neutral and Positive stimuli were faster in S1 for Scene training, while the opposite pattern was found for Negative stimuli in the central sessions (S2 and S3). Responses for these latter stimuli were faster compared to Positive and Neutral ones.

DISCUSSION

Here we have analyzed how performance in an adaptive cognitive training regime based on the single n-back task interacts with emotional stimuli (scenes and faces) varying in their valence (negative, positive, and neutral). Participants were divided in two training groups for completing four sessions across two weeks. The percentage of improvement for each condition was computed. The maximum n-back level achieved in each session and the related reaction times (RTs) were also registered. The general conclusion is that cognitive performance is relatively unaltered by the emotional content of the processed information. Therefore, our hypothesis predicting interactive effects between cognition and emotion at low levels of processing complexity is not confirmed. Nevertheless, there are some further issues that deserve comment.

Firstly, the percentage of correct responses was similar for both types of training and for all the considered valences (range from 50.71% to 55.89%). These values were greater than those reported in previous studies. Thus, for instance, Colom et al., (2013) found an improvement of 41% in their single n-back training with neutral visuospatial stimuli (4 sessions). Therefore, our findings suggest that higher performance levels can be achieved using emotional stimuli.

Secondly, no differences were found between faces and scenes in terms of achieved n-back level. Nevertheless, results suggest that RTs were sensitive to emotional content to some extent (Grim, Weigand, Kazzer, Jacobs & Bajbouj, 2012; Kensinger & Corkin, 2003). However, emotion and type of training interact. There were no effects of valence for Scene training, a result in tension with previous studies where positive and negative scenes showed a facilitating effect in a dual n-back task (Lindström & Bohlin, 2011). Note that the n-back version applied here differs from Lindström and Bohlin, which preclude a direct comparison.

Third, we found that negative faces were processed faster than neutral and positive faces in the first sessions (S1 to S3). These results were inconsistent with previous studies using emotional versions of the n-back task. For example, Kensinger and Corkin found shorter RTs for neutral stimuli (fearful faces) than for negative stimuli. However, they (a) used fearful faces that are probably more ambiguous than disgust faces (Tracy & Robins, 2008) and (b) mixed fearful faces with neutral faces in the same trials. Therefore, further studies are required to know if there are differences in the effects of distinguishable negative expressions (e.g. anger, disgust, fear, sadness) regarding n-back performance.

Fourth, faster RTs to negative faces (disgust) are consistent with the so-called negativity bias (Cacioppo & Gardner, 1999). This bias refers to the fact that aversive

events evoke quick or prominent emotional responses (involving cognitive and physiological changes) than neutral or positive stimuli (Carretié et al., 2001, 2004; Ito, Larsen, Smith & Cacioppo 1998). This has adaptive and evolutionary advantages: slow reactions to dangerous or threatening events are more dramatic than to neutral or appetitive stimuli (Ekman, 1992; Öhman, Hamm, & Hugdahl, 2000).

But why negative bias was only found for faces? We can speculate that faces are omnipresent in everyday life and they have an important role in social interactions (Frith, 2007). Faces have a communicative function and intrinsic affective meaning (Izard, 1992), which is lacking from the emotional scenes employed here (Carretié et al., 2013). However, we underscore that this emotional effect vanished for the more cognitively demanding n-back condition. Why? We suggest two candidate explanations: (a) the highest difficulty level achieved in the last training session exhausted participants' short-term storage capacity, and, therefore, emotion becomes irrelevant for performance (there are no resources left for emotional processing), or (b) the effect of emotion may suffer from some sort of habituation effect across sessions and, thus, emotion may no longer be relevant at the end of the training.

In summary, the general conclusion that might be obtained after the results observed here is that the emotional content of the information to be processed is of little relevance. Improvements in cognitive performance levels across training sessions is insensitive to negative, neutral, or positive stimuli. Reaction time measures revealed some interaction, especially for negative faces at intermediate levels of processing complexity, but RTs findings were also massively negligible. This general pattern of results suggest that adaptive working memory training is unaffected by the use of emotional or neutral information.

REFERENCES

- Achaibou, A., Pourtois, G., Schwartz, S., & Vuilleumier, P. (2008). Simultaneous recording of EEG and facial muscle reactions during spontaneous emotional mimicry. *Neuropsychologia*, 46, 1104-1113.
- Ackerman, P. L., Beier, M. E., & Boyle, M. O. (2005). Working memory and intelligence: The same or different constructs?. *Psychological bulletin*, 131, 30-60.
- Aguado, L., Valdés-Conroy, B., Rodríguez, S., Román, F. J., Diéguez-Risco, T., & Fernández-Cahill, M. (2012). Modulation of early perceptual processing by emotional expression and acquired valence of faces: An ERP study. *Journal of Psychophysiology*, 26, 29.
- Aguado, L., Román, F. J., Rodríguez, S., Diéguez-Risco, T., Romero-Ferreiro, V., & Fernández-Cahill, M. (2013). Learning of Facial Responses to Faces Associated with Positive or Negative Emotional Expressions. *The Spanish journal of psychology*, 16, E24.
- Beck, S. J., Hanson, C. A., Puffenberger, S. S., Benninger, K. L., & Benninger, W. B. (2010). A controlled trial of working memory training for children and adolescents with ADHD. *Journal of Clinical Child & Adolescent Psychology*, 39, 825-836.
- Bergmann, H.K., Rijpkema, M., Guillén-Fernández, G., & Kessels, R. P. C. (2012). The Effects of Valence and Arousal on Associative Working Memory and Long-Term Memory. *PLoS ONE* 7(12): e52616.

- Britton, J. C., Taylor, S. F., Sudheimer, K. D., & Liberzon, I. (2006). Facial expressions and complex IAPS pictures: common and differential networks. *Neuroimage*, 31, 906-919.
- Buchanan, T., & Adolphs, R. (2003). The role of the human amygdala in emotional modulation of long-term declarative memory. In S. Moore & M. Oaksford (Eds.), *Emotional cognition: From brain to behavior* (pp. 9-34). London: John Benjamins.
- Buschkuehl, M., Hernandez-Garcia, L., Jaeggi, S. M., Bernard, J. A., & Jonides, J. (2014). Neural effects of short-term training on working memory. *Cognitive, Affective, & Behavioral Neuroscience*, 14, 147-160.
- Cacioppo, J. T., & Gardner, W. L. (1999): Emotion. *Annual Review of Psychology*, 50, 191–214.
- Carretié, L., Hinojosa, J. A., Martín-Loeches, M., Mercado, F., & Tapia, M. (2004). Automatic attention to emotional stimuli: neural correlates. *Human brain mapping*, 22, 290-299.
- Carretié, L., Hinojosa, J. A., & Mercado, F. (2003). Cerebral patterns of attentional habituation to emotional visual stimuli. *Psychophysiology*, 40(3), 381-388.
- Carretié, L., Kessel, D., Carboni, A., López-Martín, S., Albert, J., Tapia, M., ... & Hinojosa, J. A. (2013). Exogenous attention to facial vs non-facial emotional visual stimuli. *Social cognitive and affective neuroscience*, 8, 764-773.
- Charles, S. T., Mather, M., & Carstensen, L. L. (2003). Aging and emotional memory: The forgettable nature of negative images for older adults. *Journal of Experimental Psychology: General*, 132, 310–324.

- Coan, J. A., & Allen, J. J. (2007). *Handbook of emotion elicitation and assessment*. Oxford university press.
- Colom, R., Abad, F. J., Quiroga, M^a A., Shih, P. C. & Flores-Mendoza, C. (2008). Working memory and intelligence are highly related constructs, but why? *Intelligence*, 36, 584-606.
- Colom, R., Quiroga, M., Shih, P. C., Martínez, K., Burgaleta, M., Martínez-Molina, A., ... & Ramírez, I. (2010). Improvement in working memory is not related to increased intelligence scores. *Intelligence*, 38(5), 497-505.
- Colom, R., Román, F. J., Abad, F. J., Shih, P. C., Privado, J., Froufe, M., ... & Jaeggi, S. M. (2013). Adaptive n-back training does not improve fluid intelligence at the construct level: Gains on individual tests suggest that training may enhance visuospatial processing. *Intelligence*, 41, 712-727.
- Colom, R., Shih, P.C., Flores-Mendoza, C. & Quiroga, M^a A. (2006). The real relationship between short-term memory and working memory. *Memory*, 14, 804-813.
- Cowan, N., Elliott, E. M., Scott Saults, J., Morey, C. C., Mattox, S., Hismjatullina, A., & Conway, A. R. (2005). On the capacity of attention: Its estimation and its role in working memory and cognitive aptitudes. *Cognitive psychology*, 51, 42-100.
- Chooi, W. T., & Thompson, L. A. (2012). Working memory training does not improve intelligence in healthy young adults. *Intelligence*, 40, 531-542.
- Eastwood, J.D., Smilek, D., Merikle, P.M. (2003). Negative facial expression captures attention and disrupts performance. *Attention, Perception, and Psychophysics*, 65, 352-8.

- Ebner, N. C., Riediger, M., & Lindenberger, U. (2010). FACES—A database of facial expressions in young, middle-aged, and older women and men: Development and validation. *Behavior Research Methods*, 42, 351-362.
- Ekman, P. (1992). An argument for basic emotions. *Cognition & Emotion*, 6, 16-200.
- Fandakova, Y., Shing, Y. L., & Lindenberger, U. (2012). Heterogeneity in memory training improvement among older adults: A latent class analysis. *Memory*, 20, 554-567.
- Frith C. D. (2007). The social brain? *Philosophical Transactions of the Royal Society*, 362, 671–678
- Gotoh, F. (2008). Influence of affective valence on working memory processes , *International Journal of Psychology*, 43, 59-71.
- Gray, J. R. (2001). Emotional modulation of cognitive control: Approach/withdrawal states double-dissociate spatial form from verbal two-back task performance. *Journal of Experimental Psychology: General*, 130, 436–452.
- Gray, J. R., Braver, T. S., & Raichle, M. E. (2002). Integration of emotion and cognition in the lateral prefrontal cortex. *Proceedings of the National Academy of Sciences of the USA*, 99, 4115–4120.
- Grim, S., Weigand, A., Kazzer, P., Jacobs, A. M., & Bajbouj, M. (2012). Neural mechanisms underlying the integration of emotion and working memory. *NeuroImage*, 61, 1188-1194.

- Guastella, A. J., Mitchell, P. B., & Mathews, F. (2008). Oxytocin enhances the encoding of positive social memories in humans. *Biological psychiatry*, 64, 256-258.
- Holmes, A., Nielsen, M. K., Tipper, S., & Green, S. (2009). An electrophysiological investigation into the automaticity of emotional face processing in high versus low trait anxious individuals. *Cognitive, Affective, & Behavioral Neuroscience*, 9, 323-334.
- Ito, T. A., Larsen, J. T., Smith, N. K., & Cacioppo, J. T. (1998). Negative information weighs more heavily on the brain: the negativity bias in evaluative categorizations. *Journal of Personality and Social Psychology*, 75, 887-900.
- Izard, C.E. (1992). Basic emotions, relations among emotions, and emotion-cognition relation. *Psychological Review*, 99, 561-565.
- Jaeggi, S. M., Buschkuhl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proceedings of the National Academy of Sciences*, 105, 6829-6833.
- Jaeggi, S. M., Buschkuhl, M., Perrig, W. J., & Meier, B. (2010b). The concurrent validity of the N-back task as a working memory measure. *Memory*, 18, 394-412.
- Jaeggi, S. M., Studer-Luethi, B., Buschkuhl, M., Su, Y. F., Jonides, J., & Perrig, W. J. (2010a). The relationship between n-back performance and matrix reasoning—Implications for training and transfer. *Intelligence*, 38, 625-635.
- Jaeggi, S. M., Buschkuhl, M., Jonides, J., & Shah, P. (2011). Short- and long-term benefits of cognitive training. *Proceedings of the National Academy of Sciences, U.S.A.*, 108, 10081-10086.

- Jaušovec, N., & Jaušovec, K. (2012). Working memory training: improving intelligence—changing brain activity. *Brain and cognition*, 79, 96-106.
- Jolles, D. D., Grol, M. J., Van Buchem, M. A., Rombouts, Serge A.R.B., Crone, E. A. (2010). Practice effects in the brain: Changes in cerebral activation after working memory practice depend on task demands. *NeuroImage*, 52, 658–668.
- Kensinger, E. A., & Corkin, S. (2003). Effect of negative emotional content on working memory and long-term memory. *Emotion*, 3, 378–393.
- Klingberg, T., Fernell, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlström, K., ... & Westerberg, H. (2005). Computerized training of working memory in children with ADHD-a randomized, controlled trial. *Journal of the American Academy of Child & Adolescent Psychiatry*, 44, 177-186.
- Lang, P., & Bradley, M. M. (2007). The International Affective Picture System (IAPS) in the study of emotion and attention. *Handbook of emotion elicitation and assessment*, 29-46.
- Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2005). International affective picture system (IAPS): *Affective ratings of pictures and instruction manual*. NIMH, Center for the Study of Emotion & Attention.
- Levens, S. M., & Gotlib, I. H. (2010). Updating positive and negative stimuli in working memory in depression. *Journal of Experimental Psychology: General*, 139, 654.
- Levens, S. M., & Gotlib, I. H. (2012). The effects of optimism and pessimism on updating emotional information in working memory. *Cognition & emotion*, 26, 341-350.

- Lindström, B. R., & Bohlin, G. (2011): Emotion processing facilitates working memory performance, *Cognition & Emotion*, 25, 1196-1204.
- Lundqvist D., & Litton J. E. (1998). "The Averaged Karolinska Directed Emotional Faces". KDEF, CD ROM. Stockholm, Sweden: Department of Clinical Neuroscience, Psychology Section, Karolinska Institutet, ISBN 91-630- 7164-9.
- Martínez, K., Burgaleta, M., Román, F. J., Escorial, S., Shih, P. C., Quiroga, M. Á., & Colom, R. (2011). Can fluid intelligence be reduced to 'simple' short-term storage?. *Intelligence*, 39, 473-480.
- McKendrick, R., Ayaz, H., Olmstead, R., & Parasuraman, R. (2014). Enhancing dual-task performance with verbal and spatial working memory training: continuous monitoring of cerebral hemodynamics with NIRS. *Neuroimage*, 85, 1014-1026.
- Öhman, A., Hamm, A., & Hugdahl, K. (2000). Cognition and the autonomic nervous system: orienting, anticipation, and conditioning. In: Cacioppo, J. T., Tassinary, L. G., Bernston, G. G., (Eds). *Handbook of psychophysiology*, (pp 533–575). Cambridge, Cambridge University Press
- Olesen, P. J., Westerberg, H., & Klingberg, T. (2004). Increased prefrontal and parietal activity after training of working memory. *Nature neuroscience*, 7, 75-79.
- Olofsson, J. K., Nordin, S., Sequeira, H., & Polich, J. (2008). Affective picture processing: an integrative review of ERP findings. *Biological psychology*, 77, 247-265.
- Pillemer, D. B., Goldsmith, L. R., Panter, A. T., & White, S. H. (1988). Very long-term memories of the 1st year in college. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 14, 709–715

- Redick, T. S., Shipstead, Z., Harrison, T. L., Hicks, K. L., Fried, D. E., Hambrick, D. Z., ... & Engle, R. W. (2013). No evidence of intelligence improvement after working memory training: A randomized, placebo-controlled study. *Journal of Experimental Psychology: General*, 142, 359-379.
- Shipstead, Z., Redick, T. S., & Engle, R. W. (2012). Is working memory training effective?. *Psychological bulletin*, 138, 628-654.
- Stephenson, C. L., & Halpern, D. F. (2013). Improved matrix reasoning is limited to training on tasks with a visuospatial component. *Intelligence*, 41, 341-357.
- Subramaniam, K., Luks, T. L., Fisher, M., Simpson, G. V., Nagarajan, S., & Vinogradov, S. (2012). Computerized cognitive training restores neural activity within the reality monitoring network in schizophrenia. *Neuron*, 73, 842-853.
- Takeuchi, H., Taki, Y., Sassa, Y., Hashizume, H., Sekiguchi, A., Fukushima, A., & Kawashima, R. (2011). Working memory training using mental calculation impacts regional gray matter of the frontal and parietal regions. *PLoS One*, 6, e23175.
- Tracy, J.L. & Robins, R.W. (2008). The automaticity of emotion recognition. *Emotion*, 8, 81-95
- Twamley, E. W., Jeste, D. V., & Bellack, A. S. (2003). A review of cognitive training in schizophrenia. *Schizophrenia Bulletin*, 29, 359.
- Zelinski, E. M. (2009). Far transfer in cognitive training of older adults. *Restorative neurology and neuroscience*, 27, 455-471.

FIGURE LEGENDS.

Figure 1. Design of the n-back task employed for all emotional categories in faces training.

Figure 2. Design of the n-back task employed for all emotional categories in scenes training.

Figure 3. N-back level achieved in each session for both training programs (Scenes and Faces) and for all emotional conditions (Negative, Neutral and Positive).

Figure 4. Reaction times (RTs) for each session in both training programs (Scenes and Faces) and for all emotional conditions (Negative, Neutral and Positive).

	N-back level		
	<i>F</i>	<i>p</i>	η^2
<i>Training</i>	1.325	0.252	0.013
<i>Emotion</i>	0.259	0.772	0.003
<i>Session</i>	316.328**	< .001	0.758
<i>Training * Emotion</i>	0.025	0.975	0.001
<i>Training * Session</i>	1.635	0.205	0.016
<i>Emotion * Session</i>	1.112	0.354	0.011
<i>Training * Emotion * Session</i>	0.193	0.931	0.002
	Reaction Times (RTs)		
	<i>F</i>	<i>p</i>	η^2
<i>Training</i>	0.329	0.568	0.003
<i>Emotion</i>	12.825**	< .001	0.113
<i>Session</i>	20.585**	< .001	0.169
<i>Training * Emotion</i>	5.545*	0.007	0.052
<i>Training * Session</i>	6.008*	0.002	0.056
<i>Emotion * Session</i>	2.245*	0.038	0.022
<i>Training * Emotion * Session</i>	0.863	0.489	0.008

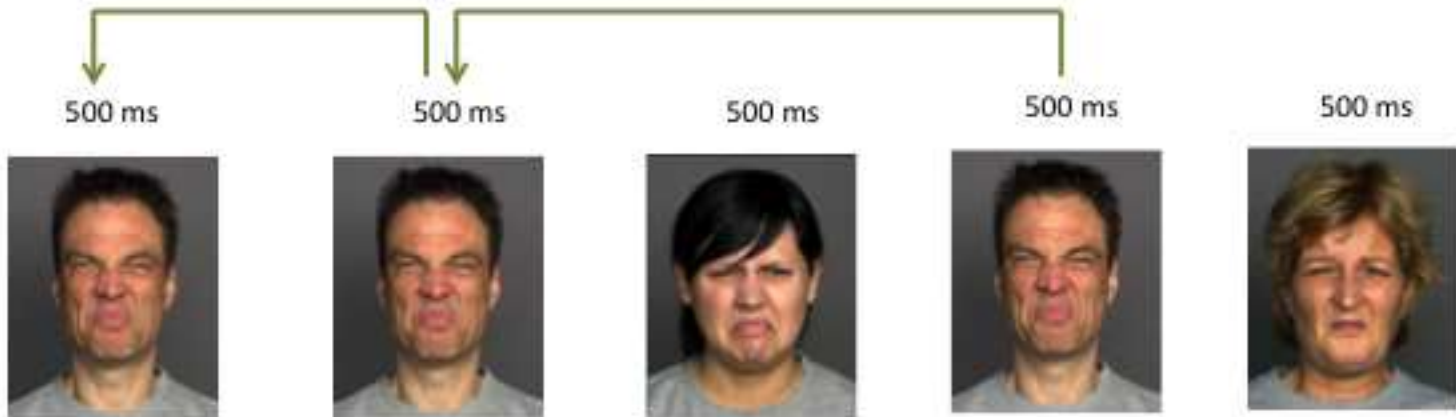
p* < .05; *p* < .001

Table 1. Mixed ANOVA results for n-back performance and reaction times (RTs).

Example: 1-Back

Example: 2-Back

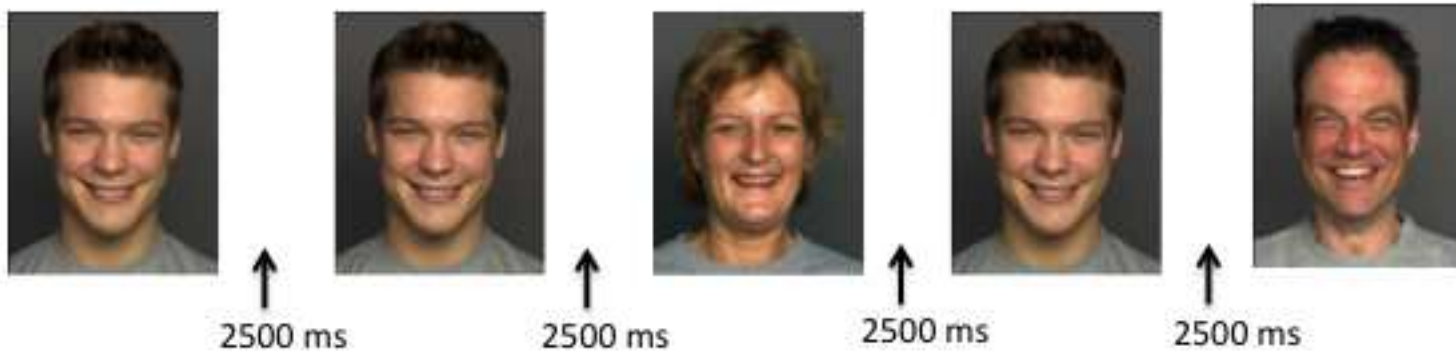
Negative



Neutral



Positive



Number of Faces in each block = $20 + n$ back. Examples: $20 + 2 = 22$ faces.

Example: 1-Back

Example: 2-Back

Negative



Neutral



Positive



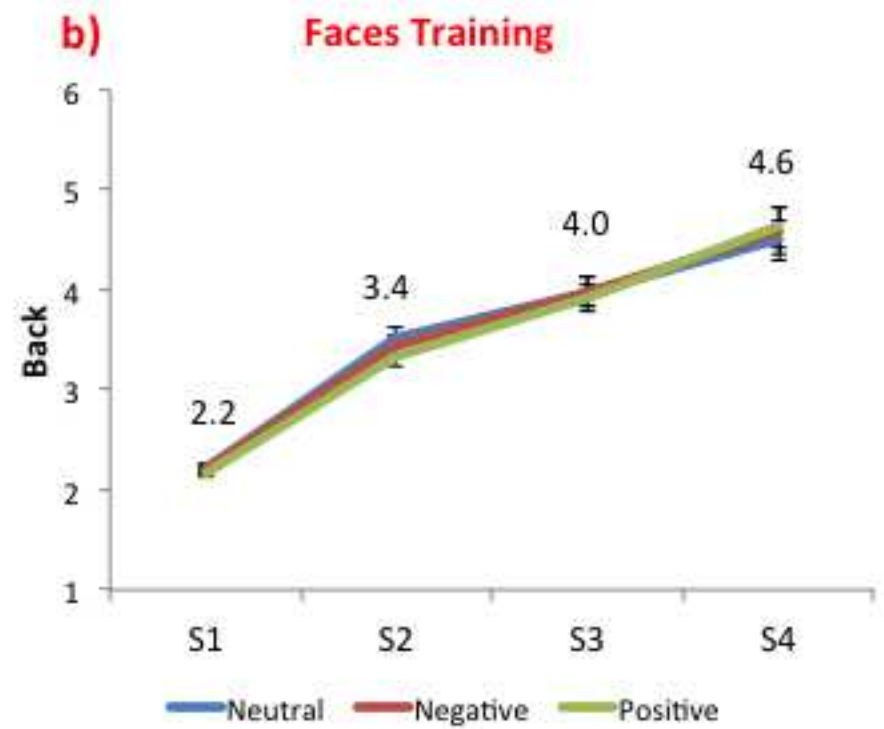
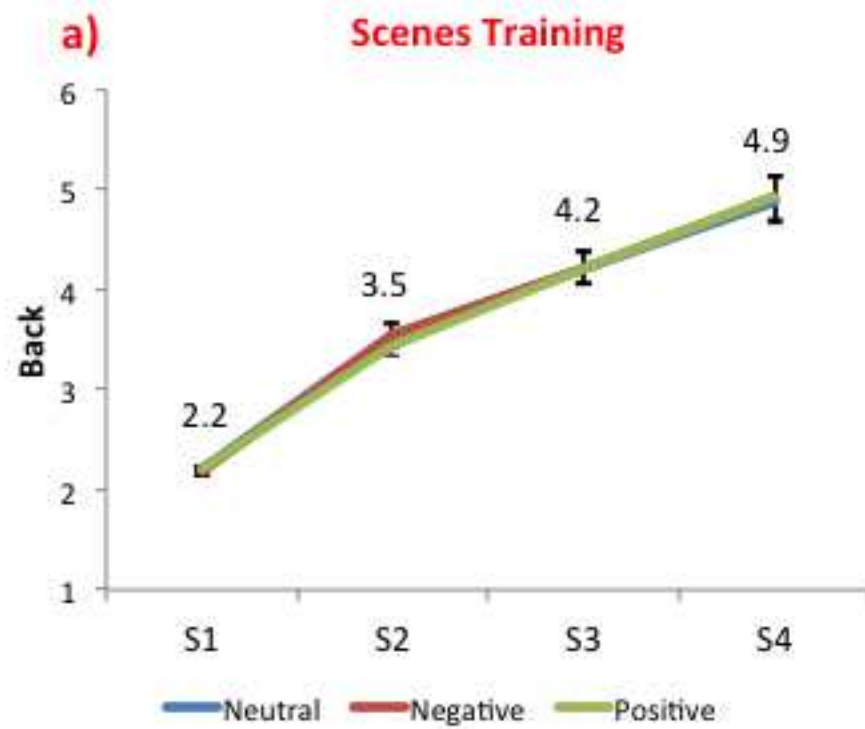
2500 ms

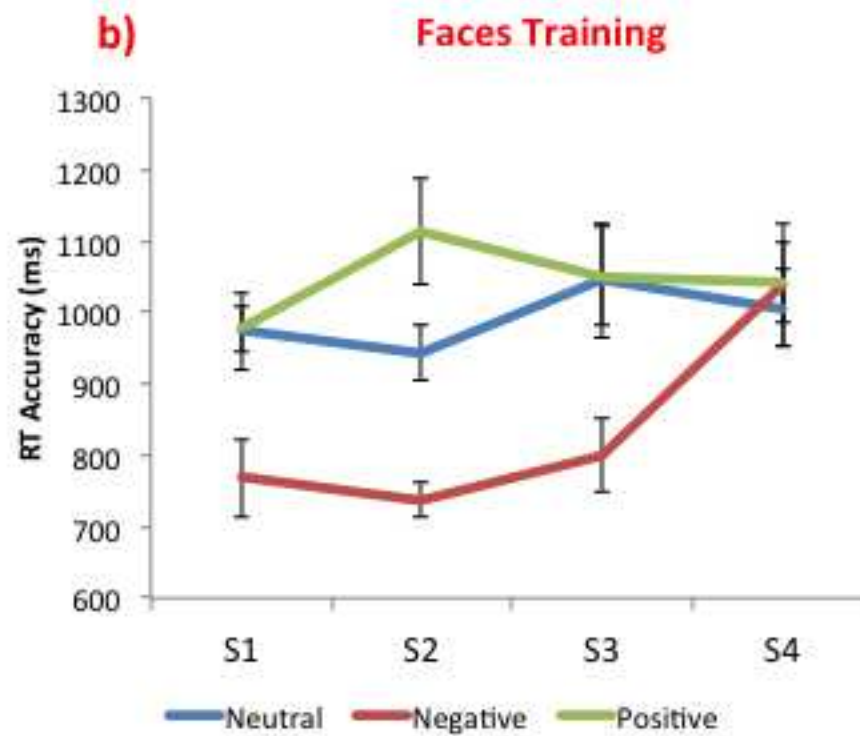
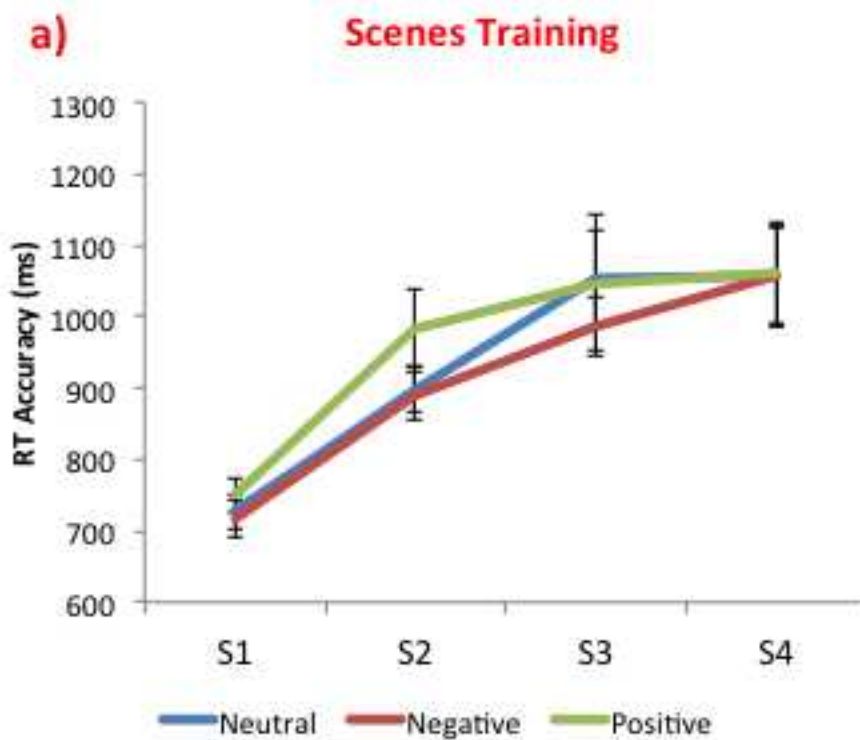
2500 ms

2500 ms

2500 ms

Number of Scenes in each block = $20 + n$ back. Examples: $20 + 2 = 22$ scenes.





Acknowledgement

This research was supported by CEMU-2012-004 (Universidad Autónoma de Madrid).

FJR is supported by BES-2011-043527 (Ministerio de Ciencia e Innovación, Spain).

MJGR is supported by FPI-UAM 2012 (Universidad Autónoma de Madrid). KM is

supported by AP2008-00433 (Ministerio de Educación, Spain). DK is supported by

AP2008-00323 (Ministerio de Educación, Spain). RC is also supported by Grant

PSI2010-20364 (*Ministerio de Ciencia e Innovación, Spain*).