Changing interpretations of emotional expressions in working memory with aging

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Abstract

Working memory (WM) shows significant decline with age. It is interesting to note that some research has suggested age-related impairments can be reduced in tasks that involve emotion-laden stimuli. However, only a few studies have explored how WM for emotional material changes in aging. Here we developed a novel experimental task to compare and contrast how emotional material is represented in older versus younger adults. The task enabled us to separate overall WM accuracy from emotional biases in the content of affective representations in WM. We found that, in addition to overall decline in WM performance, older adults showed a systematic positivity bias in representing information in WM relative to younger adults (positivity effect). They remembered fearful faces as being less fearful than younger adults and interpreted ambiguous facial expressions more positively. The findings show that aging brings a type of positivity bias when picking up affective information for guiding future behaviour.

Keywords: Emotion, working memory, aging, positivity bias, facial expressions

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Working memory (WM) is an essential cognitive function, enabling us to hold information in mind for goal-oriented behavior (Baddeley & Hitch, 1974). It plays a role in a wide range of cognitive processes including attention (Desimone & Duncan, 1995) and planning (Baddeley & Hitch, 1974). WM has highly limited capacity, which shows significant declines with age (Cowan, Naveh-Benjamin, Kilb, & Saults, 2006). Given its fundamental role across cognitive domains, this can have deleterious effects on everyday life (Davis, Marra, Najafzadeh, & Liu-Ambrose, 2010). However, a growing body of research suggests that WM capacity is not fixed, and can be modulated by factors such as attention (Griffin & Nobre, 2003; Landman, Spekreijse, & Lamme, 2003). Notably, recent studies have demonstrated that older adults retain flexibility over WM, where the ability to use attention to improve WM performance shows little age-related impairment (Gilchrist, Duarte, & Verhaeghen, 2015; Mok, Myers, Wallis, & Nobre, 2016; Newsome et al., 2015; Souza, 2016). However, these studies have used affectively neutral stimuli, which leaves open the possibility that stimulus content might also influence WM performance in older adults.

WM may also be modulated by affective content, but only a few studies have explored this in the context of aging (Bermudez & Souza, 2017; Hartley, Ravich, Stringer, & Wiley, 2015; Mammarella, Borella, Carretti, Leonardi, & Fairfield, 2013; Mikels, Larkin, Reuter-Lorenz, & Cartensen, 2005; Truong & Yang, 2014). Findings from perceptual and long-term memory tasks suggest that older adults retain sensitivity to the emotional valence of stimuli. Considerable research has shown that negatively valenced stimuli can capture attention and boost perceptual performance in younger adults (emotional salience effect; e.g. Öhman, Flykt, & Esteves, 2001; Phelps, Ling, & Carrasco, 2006), and this boost seems to be retained in older adults (Fung & Carstensen, 2003; Mather & Knight, 2006; Murphy &

Isaacowitz, 2008; Rösler et al., 2005). Both younger and older adults show better long-term memory for emotional compared to neutral stimuli (e.g. Kensinger, Brierley, Medford, Growdon, & Corkin, 2002). Whereas younger adults put more weight on negative aspects of the environment, older adults have a tendency to attend to positive information (positivity effect) (Mather & Carstensen, 2005; Reed, Chan, & Mikels, 2014). Older adults show superior performance on perceptual and memory tasks that use positive compared to neutral or negative stimuli (e.g. Charles, Mather, & Carstensen, 2003; Ebner & Johnson, 2009; Kellough & Knight, 2012; Reed, Chan, & Mikels, 2014).

Less is understood about the influence of stimulus valence on WM in older adults. Several studies found a benefit in WM performance for negative compared to neutral stimuli in younger adults (e.g. Jackson, Wu, Linden, & Raymond, 2009). A few studies have tested the interaction between affective content in WM and aging (Bermudez & Souza, 2017; Hartley et al., 2015; Mammarella et al., 2013; Mikels et al., 2005; Truong & Yang, 2014). These studies are limited to paradigms that use reaction-time (RT) measures, which are not ideal for testing older populations, who may have motor problems, or accuracy measures that cannot tease apart critical questions: namely, whether age-related changes are due to a reduction in WM capacity (independent of emotional content), or a change in how emotional information-representation is represented in WM (as more or less positive or negative). For example, higher accuracy for positive versus negative stimuli might reflect better memory for positive stimuli, a tendency to see positive things as more positive, or a tendency to see negative stimuli as less negative.

In this study, we developed a new way to measure the quality of WM representations for emotional material and to assess systematic affective biases in perceiving and interpreting emotional material, for a more sensitive test of the positivity effect in aging. The task borrows from WM precision tasks, which test WM for items with features that vary continuously along a given dimension (e.g., bars with orientation of 1°-180°), where participants recall the feature (orientation) stored in memory (Bays & Husain, 2008; Zhang & Luck, 2008). The task produces sensitive estimates of the quantity and quality of items in WM (Zokaei, Burnett Heyes, Gorgoraptis, Budhdeo, & Husain, 2015). It is also possible to identify systematic biases in the patterns of responses (e.g., a bias to report clockwise or anti-clockwise). We used facial expressions morphed from neutral to fearful and neutral to happy to test age-related changes in WM for emotional material. Facial expressions were chosen in order to produce a set of stimuli that varied on a continuous scale of positive and negative emotion. Happy faces and fearful faces were selected after consideration of their common use in previous studies on affective attentional biases (e.g. Fox, 2002; Pourtois, Grandjean, Sander, & Vuilleumier, 2004) and studies that found a relationship between attentional biases for fear-related stimuli (including faces) in anxiety (Yiend, 2010).

In the current emotion WM task, participants encoded a face into WM with an emotional expression (fearful or happy) with a certain emotional intensity. After a delay, participants used a mouse to adjust a facial expression to match the emotion type and intensity in memory. In a separate perceptual emotion-matching experiment, participants adjusted one face to match the expression of another face on the screen. Using these tasks, we compared performance accuracy and emotional bias between groups of older and younger participants to test how WM and perception for emotional material change with age. Given previous work, we might expect preserved facilitation in tasks with emotional stimuli, or only for positive stimuli, to generalise to WM and therefore mitigate against age-related deficits in WM performance in older adults. Furthermore, we might expect to measure a systematic shift in reporting the valence and emotional intensity of emotional expressions in WM, whereby fearful faces would be reported as less fearful and/or happy faces as more positive.

Method

Participants

Fifty-four young participants and 54 older participants volunteered to participate in the study and received compensation and travel expenses where required. The study was approved by the Central University Research Ethics Committee of the University of Oxford, and was carried out in accordance with the provisions of the World Medical Association Declaration of Helsinki (World Medical Association Declaration of Helsinki, 2013). Before taking part in the study, individuals were sent an electronic screening questionnaire, which included a trait anxiety questionnaire (State-Trait Anxiety Inventory, trait version) and a series of questions. People who reported current use of psychoactive medication, history of recreational drug use, history of neurological illness, or took part in studies involving WM training or emotional face stimuli in the past six months were not invited to participate. Data from one elderly participant were excluded because of a low score on the Montreal Cognitive Assessment (less than 26; Nasreddine et al., 2005), and data from two other elderly participants were not saved because of a technical error. After excluding these participants, there were 54 younger adults (39 female, *M*age=23.42 *SEM*=.60, age range: 18-35 years) and 51 older adults (29 female, *M*age=69.25±.78, age range: 61-82 years) were included in the current study. All remaining participants were fluent in English, had normal or corrected-to-normal vision and hearing, and all older participants scored >26 on the Montreal Cognitive Assessment (MoCA; *M*=28.16 *SEM*=.16; younger adults did not complete the MoCA). Sample sizes were determined with the aim of comparing performance between age groups and investigate the relationship between anxiety and behavioural measures. A survey of studies testing age differences in WM for emotional material that presented sufficient information for a power analysis (Mammarella et al., 2013; Truong & Yang, 2014) revealed that a minimum of 11 to 30 participants per group are required for 80% power, and a minimum of 14 to 41 participants per group are required for 90% power. A survey of previous studies that reported a relationship between measures of anxiety and attentional bias (using Pearson's correlation) shows that the average correlation coefficient was 0.315 (Bradley, Mogg, & Millar, 2000; Fox, Cahill, & Zougkou, 2010; Fox, Mathews, Calder, & Yiend, 2007). A power calculation indicates that 77 participants will provide 80% power of finding a significant effect (Hulley, Cummings, Browner, Grady, & Newman, 2013). Our sample of 105 provides 90% power.

Stimuli and Apparatus

Stimuli were adapted from faces in the NimStim Stimulus Set (http://www.macbrain.org/resources.htm) with permission. Forty-eight face stimuli (three emotional expressions for each of 16 identities) were selected. Happy, fearful, and neutral face images were cropped with an elliptical mask and morphed from neutral to fearful and from neutral to happy in 1% steps to produce faces with graded intensities of emotional expressions from 0% to 100% (see figure S1 and S2 for examples). Ten identities were selected for the main experiment and six for the practice session. Scrambled masks were produced for each stimulus by randomly shuffling pixels within the elliptical mask (Supplementary Online Materials for details).

Task Design and Procedure

Emotion WM task. On each trial, participants encoded a face into memory and were asked to recall this face at the end of the trial. Stimuli were faces with ~~pseudo-~~randomly selected levels of emotional intensity values of 0% to 45% and 55% to 100% in 5% steps (leaving out 50%), with one set of intensity values for each emotion type (happy, fear). Emotion-type conditions were intermixed within each block (Figure 1a).

On each trial, a “GO” screen signalled to start the trial with a left mouse click. A fixation cross was presented at the center of the screen (800 ms), after which a face (500 ms) and a scrambled mask (100 ms) were presented. After a delay of 3000 ms, a test face was presented with a neutral expression (0% intensity). Participants adjusted its expression to match the emotion type and intensity of the face in memory. Participants adjusted the face with a trackball mouse, scrolling left for one emotion and right for the other emotion (happy/fear; counterbalanced across participants) and clicked to confirm their response. After each block, feedback was given (percent correct; computed by 100 minus the average deviation of responses from the target emotional intensity, or mean error). Participants were asked to fixate centrally, and, if they consistently broke fixation, they were reminded to refrain from doing so at the next break. Accuracy was stressed over reaction time. Maximum response time was 11 seconds, but participants were encouraged to respond within six seconds in the interest of time and to reduce memory degradation. At 11 seconds, the emotional intensity that was on the screen was saved as the response.

Each participant completed eight blocks of 20 trials. For each emotion type (fear, happy), each emotion intensity level was presented four times, giving 80 trials per emotion type. For each participant, facial identities were pseudo-randomly allocated over each emotion intensity condition and all 10 identities were included in both emotion-type conditions. For each identity, there were 16 trials for each emotional intensity condition (from 0% to 100% with 5% steps, excluding 50%). Since there were 19 intensities per emotion type, plus a neutral face condition (0% intensity), not all intensity conditions were presented for each identity (the smallest range was 5% to 80%, but most identities spanned 0% to 100% for both emotion types). The number of emotional intensities conditions was kept constant (80 per condition per emotion type).

Emotion-matching task. Participants were presented with a target face on the left of the screen and adjusted the face on the right to match the emotion type and intensity of the target face. As in the WM task, stimuli were happy or fearful faces with the same range of emotion intensity conditions and identities (but the pairing of emotion intensity conditions and identities were different). Emotion-type conditions were intermixed within each block (Figure S3a).

Each trial began with a "GO" screen and the trial started with a mouse click. A fixation cross was presented (800 ms), after which two faces with the same identity appeared on the left and right side of the screen. Participants adjusted the expression of the face on the right to match the emotion type and intensity of the face on the left. The right face had a neutral expression, and participants adjusted the expression using a trackball mouse. As in the WM task, feedback was given after each block, accuracy stressed over reaction time, with the same time constraints. Eye movements were not constrained.

Each participant completed two blocks of 20 trials. For each emotion type (fear, happy), each emotion intensity condition was presented twice, with 20 trials per emotion type. As with the WM task, the facial identities were randomly allocated over each emotion intensity condition. The identities associated with each emotion-intensity condition were different to those in the WM task.

Mood questionnaires. Participants completed five self-report questionnaires measuring state and trait anxiety (State-Trait Anxiety Inventory, STAI; Spielberger, 1983), Beck's Depression Inventory (BDI; Beck, 1961), and positive and negative affective states and traits (short version of the Positive and Negative Affect Scale; PANAS; Watson, Clark, & Tellegen, 1988) immediately before to the experimental session.

Data Analysis

The aim of the analyses was to characterize age-related differences in WM for emotional material in terms of error (deviation of responses from target emotional intensities), emotional bias (representing information as more positive or negative), and valence (categorical judgment of a fearful or happy face).

In both the emotion WM and emotion-matching task, the target facial expressions included 0% intensity (neutral) and ranged from 1 to 100% in 5% steps (excluding 50%) in emotional intensity of the target emotion-type, and participants could report emotional intensities which ranged from 1 to 100% of the target emotion-type (e.g., fear). They could also report the other emotion type (e.g., happy), which was recorded as a response (from -1 to -100%) or a neutral expression (0%). To calculate error, participant responses (positive or negative) were subtracted from the target emotional intensities (positive) on each respective trial, giving an error distribution – the deviation of intensities reported by participants (responses) from the actual intensity values (targets). Responses to the other emotion type produced values with a negative sign. For instance, if a target face was 50% happy and a response was 60% happy, the error was | 50 – 60 | = 10. A response of 40% happy would also yield an absolute error of 10. If a target was 20% fearful and the response was 15% fearful, the error would be | 20 – 15 | = 5. If the response was 15% happy, then the error would be | 20 – (-15) | = 35. The highest possible error would be 200 (if target face was 100% fearful and the response was 100% happy), but the maximum error decreases proportionally to the valence of the stimuli (e.g. if target face was 50% fearful, the maximum error would be 150). Error was computed by taking the mean of the absolute (positive) error values across trials. Statistical tests were also performed after excluding trials where participants reported the incorrect emotion type and trials with neutral targets. See Supplementary Online Materials

(Trial numbers) for details of excluded trials. Trials in which participants used up the maximum time for a response (11 seconds) did not have an effect of the results (for details see Supplementary Online Materials, Maximum Response Time Trials).

Emotional bias was derived from the shift in the psychometric function of responses. Participants' responses were plotted as a function of the actual emotion type and emotional intensity of the target face, with negative values representing intensities of fearful faces and positive values representing intensities of happy faces (figure 2a). Note that 'response' values are the actual emotional intensity values that participants reported, unlike the error values above which were calculated relative to the target. To obtain an overall measure of bias, we computed the mean of this curve (mean response across all intensity conditions -100% to 100%). If participants had a positive bias value, this corresponded to the tendency to report faces as either more positive or less negative (or both), a negative value would reflect the tendency to report faces as less positive or more negative (or both), and a value at zero would correspond to no bias. For instance, if a target face was 50% happy and a response was 60% happy or 40% happy, the bias value on those trials would be 10% and -10% respectively. If a target face was 20% fearful and a response was 15% happy, the bias would be 35% (15 minus -20), whereas if the target face were 15% happy face and response 20% fearful, the bias would be -35% (-20 minus 15). Note that intensity values of happy faces are positive, and values of fearful faces are negative. The most negative possible bias would be -200% (if target face was 100% happy and the response was 100% fearful) and most positive bias would be 200% (if target face was 100% fearful and the response was 100% happy), but would normally be lower than this value. Statistical tests were also performed after excluding trials where participants reported the incorrect emotion type, since trials where participants judged happy faces to be fearful might contribute to an overall negative bias, and trials where participants judged fearful faces to be happy might contribute to an overall a positive bias.

To test for biases that stem specifically from the fearful or happy face conditions, bias was computed for emotion types separately. First, responses for the fearful faces were flipped to have positive sign to be compared with happy bias values. Second, the trials with neutral faces (0% intensity) were excluded. The mean response was computed across emotional intensities for each emotion type (from 1% to 100%), then normalized by subtracting ~~by~~ 50 to match the overall bias measure, so that a bias of zero would reflect no bias.

To characterize judgments of valence (categorical judgment of fearful or happy), we separated responses into the correct and incorrect emotion type. Reporting the incorrect emotion occurred when participants adjusted the face to the wrong emotion type (e.g.. reported 25% fearful face but the target was a happy face), which were excluded in a subset of the analyses above. To inspect the effect of emotional intensity on valence judgments, trials were binned into five equal bins of emotional intensity (1–20, 21–40, 41–60, 61–80, 81–100). Proportion correct was computed for each target emotion intensity bin (e.g., proportion correct 0.7 for a given intensity bin means participants reported the correct emotion type 70% of the time and the incorrect emotion type 30% of the time).

A mixed repeated-measures ANCOVA was conducted on WM error with within-subject factor Emotion-Type (fear, happy), between-subjects factor Age (young, old), continuous factor Anxiety (STAI trait). Anxiety was included to test for the relationship between behavior and mood. A mixed repeated-measures ANCOVA was performed on emotional bias to test between-subject factor Age, with a continuous factor Anxiety. To test if bias effects were driven by happy or fearful faces, a mixed repeated-measures ANCOVA was conducted on WM bias for happy and fearful face conditions, with within-subject factor Emotion-Type, between-subjects factor Age, and a continuous factor Anxiety. For the emotion-matching task, the same ANCOVAs listed above were conducted. All ANCOVAs above were recomputed after excluding trials to the incorrect emotion type and neutral target face trials. A mixed repeated-measures ANCOVA was conducted on proportion correctly categorized faces in the emotion WM and emotion-matching task separately, with within-subject factor Emotion-Type, Intensity (1–20, 21–40, 41–60, 61–80, 81–100) between-subjects factor Age, and continuous factor Anxiety. Gender was included in all ANCOVAs as a covariate of no interest. Degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity when normality assumptions were violated.

Paired t-tests were used to test for paired condition differences, and independent samples t-tests to compare between age groups. To test for the direction of linear contrasts, we tested if slopes and differences in slopes (between emotion types) were different from zero (one-sample t-test). Cohen's d was used to determine effect sizes. Confidence intervals for Cohen's d and η_p^2 (for ANCOVAs) were calculating using the MBESS package in R (for between-subject effects), or from custom R code (for within-subject effects; from https://github.com/Lakens/perfect-t-test/blob/master/Perfect_dependent_t-test.Rmd). All analyses conducted have been reported in this section.

Statistical analyses were conducted in Matlab R2015a, Matlab's Statistics Toolbox and R version 3.2.1 (R Core Team, 2015) using the afex package (Singmann, Bolker, & Westfall, 2015) and MBESS package. The code to run the experiment (Matlab, Psychtoolbox), data analysis code (Matlab, R) and the behavioral data are available at https://osf.io/a47xe/. The authors are happy to share the data and the experimental scripts. However, before we are able to share the stimuli, which are necessary for the task, permission needs to be obtained to use the NimStim faces from the original creators. These stimuli are for research purposes only (see http://danlab7.wixsite.com/nimstim)[1].

[1] To access the stimuli, please follow the instructions in the link, forward the email with the permission to use the stimuli, and a link to download the images will be shared.

Results

Accuracy for Matching Emotional Faces in WM and perception

Participants completed the emotion WM task with high accuracy (percent error: $M_{youngfear}$=17.20, *SEM*=.48, $M_{oldfear}$=20.30, *SEM*=.53; $M_{younghappy}$=15.34, *SEM*=.53, $M_{oldhappy}$=17.13, *SEM*=.56) and showed better WM performance for happy compared to fearful faces (Emotion-Type: F(1,101)=40.20, p<.001, η_p^2=.28, 90% CI [.17, .39]). Older adults showed a general deficit in WM for emotional content (Age: F(1,101) = 14.10, p<.001, η_p^2=.12, 90% CI [.04, .22]) which was more prominent for fearful faces (Age by Emotion-Type interaction: F(1,101)=4.84, p=.03, η_p^2=.05, CI 90% [.002, .12]; young versus old fear: t(101.04)=-4.29, p<0.001, d=-.84, 95% CI [-1.24, -.44]; happy: t(102.43)=-2.31, p=.023, d=-.45, 95% CI [-0.84, -0.06]; figure 1b). The results were similar after excluding trials in which participants reported the incorrect emotion type (error: $M_{youngfear}$=16.42, *SEM*=.48, $M_{oldfear}$=18.54, *SEM*=.46; $M_{younghappy}$=11.97, *SEM*=.33, $M_{oldhappy}$=13.58, *SEM*=.40), with better performance for happy compared to fearful faces (Emotion-Type: F(1,101)=221.61, p<.001, η_p^2=.69, 90% CI [.60, .74]). Older adults were still significantly worse than the younger group (Age: F(1,101)=14.35, p<0.001, η_p^2=.12, 90% CI [.04, .22]), but there was no longer an interaction between Age and Emotion-Type (F(1,101)=.89, p=.35, η_p^2=.01, 90% CI [0, .06]).

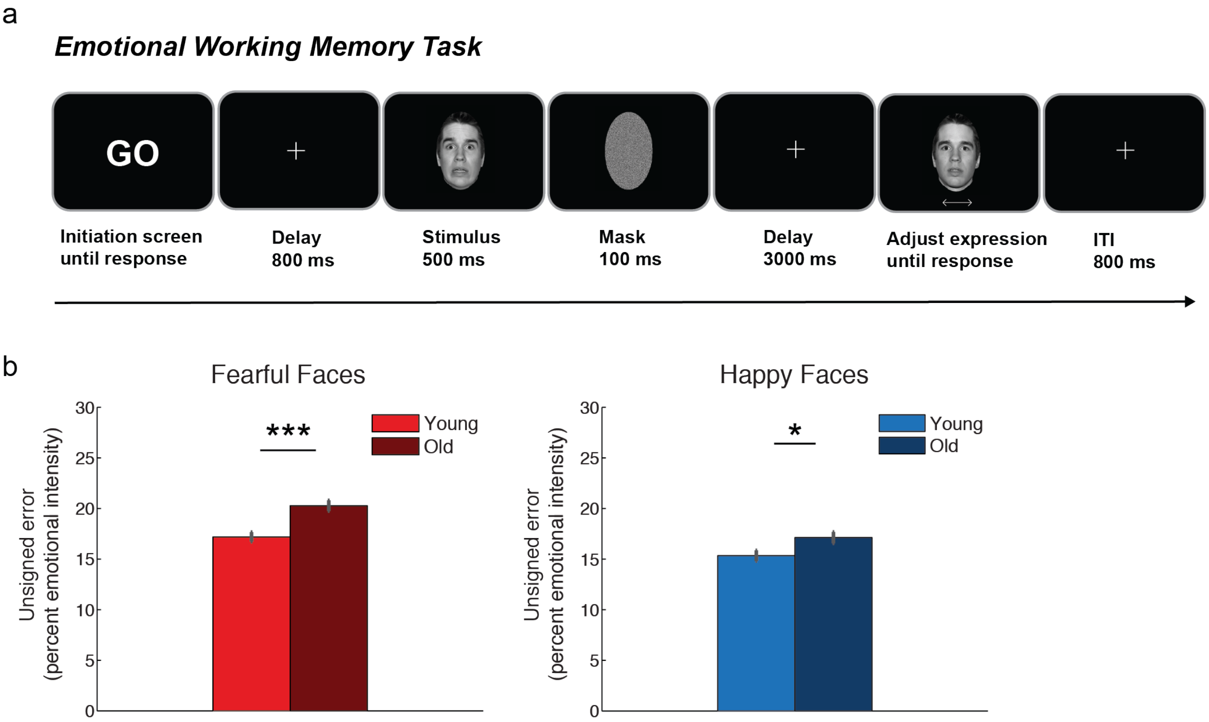

Figure 1. WM task schematic and WM error results**.** In the WM task (a), participants encoded a facial expression into WM, and maintained it over a delay of 3000 ms. A test face with the same facial identity but a neutral facial expression (0% intensity) appeared, and participants changed the face to match the expression intensity in memory using a trackball mouse. Target faces were fearful or happy faces from 0% to 100% in emotional intensity. Emotion type was intermixed within blocks. Bar plots in (b) show WM error for fearful (red, left) and happy faces (blue, right) in the young and old participant groups. Error bars represent SEM *** p<.001, * p<.05. Faces presented are part of the NimStim stimulus set, for which use for publication is permitted.

Although there were fewer trials in the perceptual-matching task, the pattern of results was similar to the WM task (error: $M_{youngfear}$=10.42, *SEM*=.42, $M_{oldfear}$=12.67, *SEM*=.52; $M_{younghappy}$=7.09, *SEM*=.34, $M_{oldhappy}$=8.15, *SEM*=.40), with better performance for happy compared to fearful matching (Emotion-Type: $F(1,101)=125.34$, $p<.001$, $\eta_p^2=.55$, 90% CI [.44, .63]). Older adults were worse than younger adults at matching the emotional faces

(Age: $F(1,101)=10.00$, $p=0.002$, $\eta_p^2=.09$, 90% CI [.02, .18]). After excluding trials in which participants erroneously reported the incorrect emotion type, the pattern of performance was similar (error: $M_{youngfear}=10.23$, $SEM=.43$, $M_{oldfear}=12.06$, $SEM=.49$; $M_{younghappy}=6.72$, $SEM=.32$, $M_{oldhappy}=7.54$, $SEM=.33$; Emotion-Type: $F(1,101)=145.48$, $p<.001$, $\eta_p^2=.59$, 90% CI [.49, .66]), with a strong effect of Age ($F(1,101)=7.40$, $p=0.008$, $\eta_p^2=.07$, 90% CI [.01, .15]).

Age-related shifts of emotional bias in WM

Younger adults exhibited a stronger negative shift in their WM psychometric curves compared to the older adults ($M_{young}=-3.25$, $SEM=.52$; $M_{old}=-1.26$ $SEM=.68$; $F(101)=6.55$, $p=.01$, $\eta_p^2=.06$, 90% CI [.007, .15]; figure 2a-b). They reported fearful faces as more emotionally intense than older adults (figure 2c; Age by Emotion-Type interaction $F(1,101)=6.27$, $p=.01$, $\eta_p^2=.06$, 90% CI [.006, .14]; young versus old fear: $t(97.51)=2.87$, $p=.005$, $d=.56$, 95% CI [.17, .95]; happy: $t(94.65)=.52$, $p=.60$, $d=.10$, 95% CI [-.28, 0.48]). After excluding responses to the incorrect emotion type, there was still a difference between age groups ($M_{young}=-2.24$, $SEM=.48$; $M_{old}=-.46$, $SEM=.61$; $F(1,101)=5.83$, $p=.02$, $\eta_p^2=.05$, 90% CI [.005, .14]), and the effect was likely due to the difference in fearful faces (Age by Emotion-Type Interaction: $F(1,101)=3.20$, $p=.08$, $\eta_p^2=.03$, 90% CI [0, 10]; young versus old fear: $t(100.5)=1.84$, $p=.069$, $d=.36$, 95% CI [-.27, .74]; younger versus old happy: $t(88.49)=.26$, $p=.79$, $d=.05$, 95% CI [-.33, .43]). There were no significant results in the perceptual-matching task for these effects (figure S4).

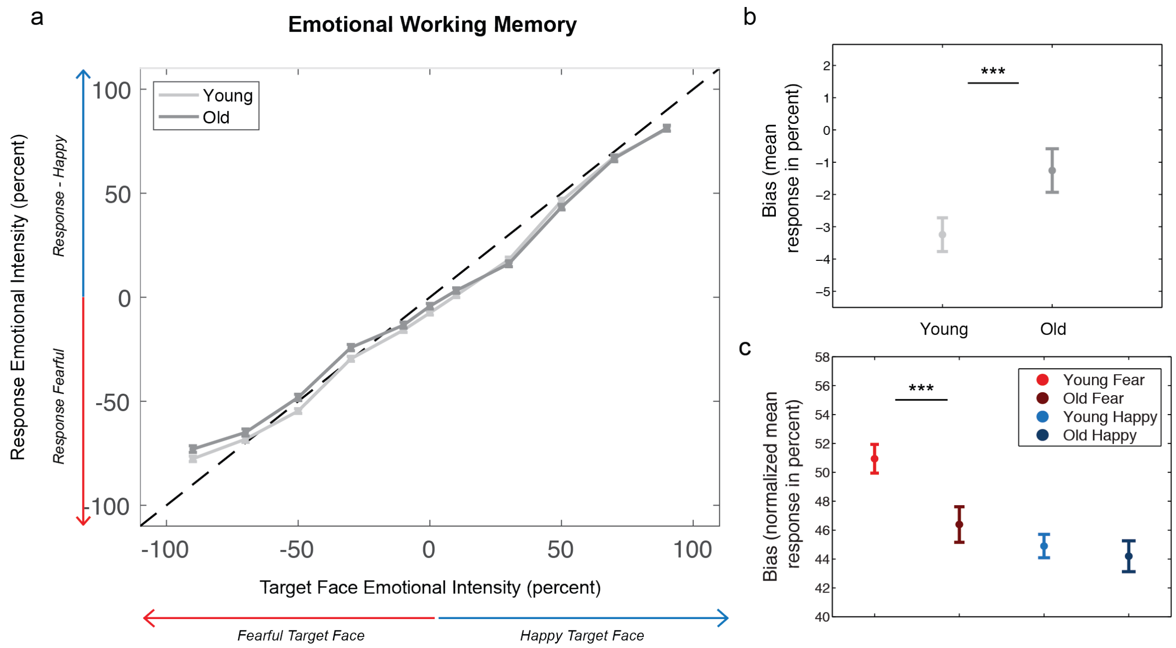

Figure 2. Emotional bias in WM**.** Responses are plotted as a function of the target face emotion type and emotional intensity in (a), with negative values representing intensity values of fearful faces and positive values representing intensity values of happy faces. Responses are binned into five equal bins for fearful faces (from -100 to -20% in 20% steps, with the 20% bin including -20 to -1%) and five bins for happy faces (from 20% to 100% in 20% steps) and a 0% bin with only neutral faces for visualization. Perfect performance corresponds to responses on the diagonal (dotted line). On the right side of zero (y-axis), responses above the line mean that faces were reported to be happier than target happy faces, whereas responses below the line mean that faces were reported to be less happy than targets. On the left side of zero, responses below the line mean that faces were reported to be more fearful than target fearful faces, whereas responses above the line mean that faces were reported as less fearful than targets. The bias is shown in (b), computed by taking the mean of each participant's raw psychometric curve (note that (a) is binned for visualization). Bias for each of the emotion types is plotted in (c). Responses for fearful faces were flipped to have positive sign, and trials with neutral faces were excluded. Mean response was computed for

each emotion type (from 1% to 100%) and normalized by subtracting 50 (see Data Analysis for details). *** $p<.001$.

Age-related changes in emotion interpretation in WM

Although participants generally reported the correct emotion type in the emotion WM task, they also mistakenly interpreted the face to have the incorrect emotion type on a sizable proportion of trials (proportion of happy faces reported fearful: M_{young}=.14, SEM=.01 / M_{old}=.12±.01, proportion of fearful faces reported happy: M_{young}=.05, *SEM*=.01, M_{old}=.08, *SEM*=.01) and on a minority of the trials in the perceptual expression-matching task (proportion of happy faces reported fearful: M_{young}=.04, *SEM*=.01, M_{old}=.05, *SEM*=.01, proportion of fearful faces reported happy: M_{young}=.04, *SEM*=.01, M_{old}=.07, *SEM*=.01). Figure 3 shows the proportion of trials in which participants reported the correct emotion type for each intensity bin (see figure S6 for scatterplots that illustrate the pattern of responses across intensities).

Participants were more likely to report the correct emotion type for fearful face trials compared to happy face trials (Emotion-type: ($F(1,101)=53.78$, $p<.001$, $\eta_p^2=.35$, 90% CI [.22, .45]). Ambiguous, low emotional intensity faces were more likely to be misinterpreted as the other emotion type ($F(1.89,191.08)=374.25$, $p<.001$; $\eta_p^2=.79$, 90% CI [.74, .82]; M_{slope}=.07, *SEM*=.003; $t(104)=23.85$, $p<.001$, $d=2.33$, 95% CI [1.96, 2.70]), and this effect was stronger for happy compared to fearful faces (Emotion-Type by Intensity: $F(1.74, 175.95)=43.57$, $p<.001$, $\eta_p^2=.30$, 90% CI [.21, .38]; happy M_{slope}=.09±.005, $t(104)=18.8$, $p<.001$, $d=1.84$, 95% CI [1.52, 2.15]; fear M_{slope}=.04, *SEM*=.004, $t(104)=11.7$, $p<.001$, $d=1.15$, 95% CI [.90, 1.39]]; $M_{slopediff}$ =.049, *SEM*=.007, $t(104)=-7.42$, $p<.001$, $d=1.09$, 95% CI [.77, 1.42]).

Crucially, older adults were more likely to judge a fearful face as a happy one in the WM task (Age by Emotion-Type interaction: $F(1,101)=10.06$, $p=.002$, $\eta_p^2=.09$, 90% CI [.02, .18]; $t(77.75)=-3.56$, $p<.001$, $d=-.70$, 95% CI [-1.09, -.30]), whereas both age groups judged happy faces as fearful to a similar extent ($t(102.98)=.80$, $p=.43$, $d=.15$, 95% CI [-.23, .54]). This effect was modulated by the emotional intensity of the face stored in WM (Age by Emotion-Type by Intensity interaction: $F(1.74,175.95)=8.17$, $p<0.001$, $\eta_p^2=.07$, 90% CI [.02, .14]), where older adults tended to judge fearful faces with low-to-medium intensities as happy compared to the younger adults ($M_{slopediff}=.02$, $SEM=.04$; $t(82.15)=2.87$, $p=.005$, $d=.56$, 95% CI [0.17, 0.95]) but not for the happy faces ($M_{slopediff}=-.01$, $SEM=.04$; $t(102.18)=-1.50$, $p=.14$, $d=-.29$, 95% CI [-.68, .09]).

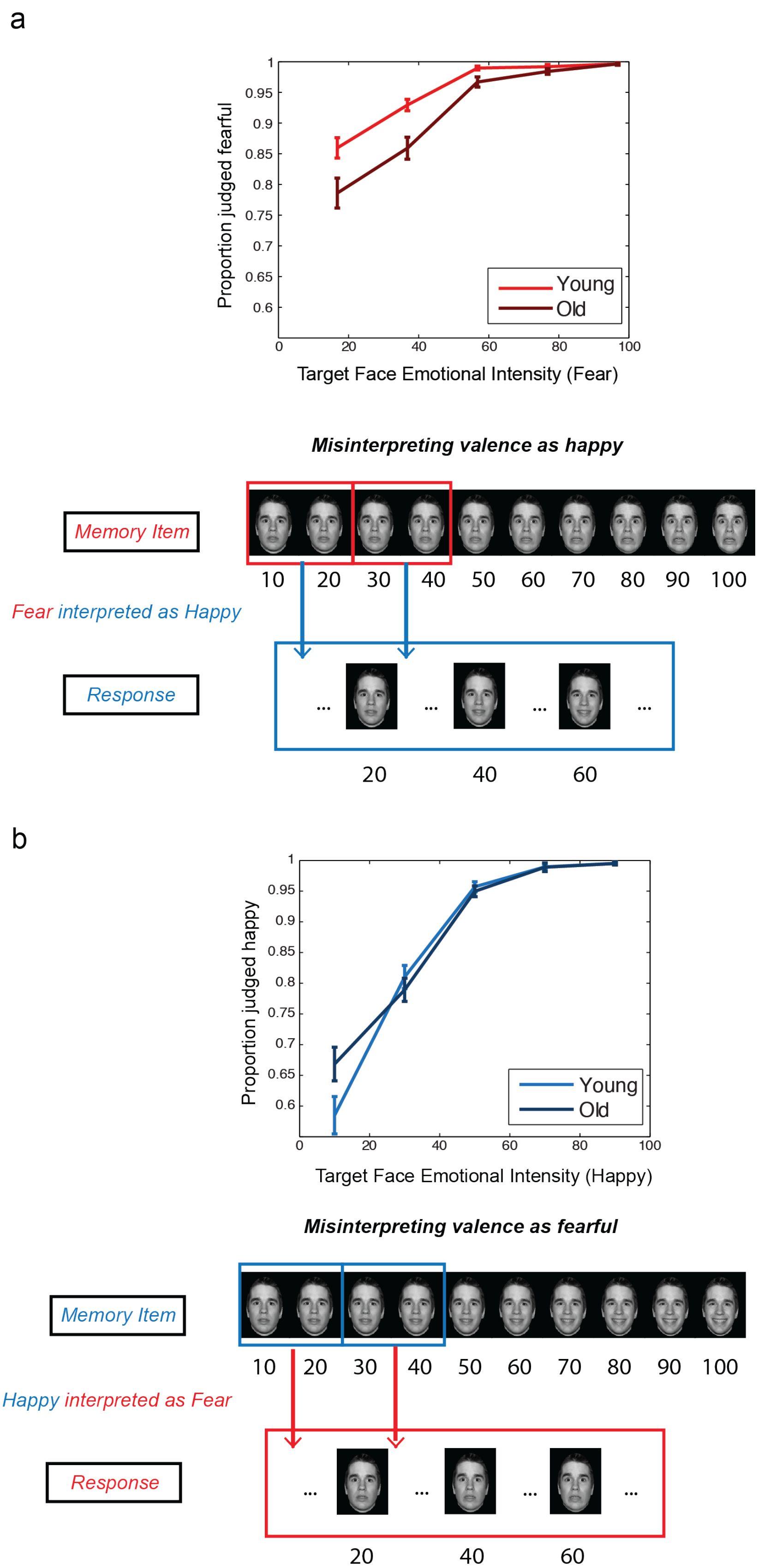

Figure 3. Older adults interpreted fearful faces with low emotional intensities as happy more than younger adults. Proportion of trials correctly judged as fearful in the WM task are

plotted for each emotional intensity bin from 1% to 80% in 20% steps for younger and older participants in the top panel in (a). An illustration showing how low-to-medium fearful faces are sometimes judged as happy faces in the bottom panel of (a). Proportion of trials correctly judged as happy in the WM task are plotted for each emotional intensity bin in the top panel of (b) for younger and older participants, with an illustration in the bottom panel showing how low-to-medium happy faces are sometimes judged as fearful faces. Faces presented are part of the NimStim stimulus set, for which use for publication is permitted.

In the perceptual-matching task, participants showed the opposite pattern for the Emotion-Type, where they mistakenly interpreted fearful faces as happy more than they judged happy faces as fearful (Emotion-Type: F(1,101)=8.71, p=.004, η_p^2=.08, 90% CI [.02, .17]). Participants incorrectly reported the emotion-type for faces with low emotional intensity (F(1.44,145.05)=63.84, p<.001, η_p^2=.39, 90% CI [.28, .47]]; M_{slope}=.03, *SEM*=.004, t(104)=10.05, p<.001, d=.98, 95% CI [.75, 1.21]) and this effect was slightly stronger for fearful compared to happy faces (F(1.59,160.68)=5.64, p=.008, η_p^2=.05, 90% CI [.01, .11]; fear M_{slope}=.05±.006, t(104)=7.56, p<.001, d=.74, 95% CI [.52, .95]; happy M_{slope}=.03±.004, t(104)=7.07, p<.001, d=.69, 95% CI [.48, .90]; $M_{slopediff}$=.015, *SEM*=.007, t(104)=2.03, p=.045, d=.27, 95% CI [.006, .54]). Notably, there was only a trend for an interaction of Emotion-Type with Age (F(1,101)=3.45, p=.07, η_p^2=.03, 90% CI [0, .11]) and no significant three-way interaction with Intensity (F(1.59,160.68)=1.96, p=.15, η_p^2=.02, 90% CI [0, .06]; figure S5).

Self- reported mood measures

There were no significant differences between age groups for measures on Trait Anxiety (t(102.4)=.97, p=.33, d=.19, 95% CI [-.19, .57]), State Anxiety (t(102.6)=.50, p=.61, d=.10, 95% CI [-.29, .48]), BDI (t(89.8)=-1.14, p=.26, d=-.22, 95% CI [-.61, 0.16]), short PANAS Positive (t(101.5)=-1.61, p=.11, d=-.31, 95% CI [-.70, 0.07]), or short PANAS Negative (t(96.9)=1.73, p=.09, d=.34, 95% CI, [-.05, 0.72]) questionnaires.

Trait Anxiety was correlated with a small number of measures in the emotion WM task, but these effects were relatively weak and inconsistent when including versus excluding trials in which participants reported the wrong emotion type. This suggests no strong relationship between our behavioral measures and trait anxiety in the present sample.

Discussion

We tested younger and older adults on novel precision emotion WM and emotion-matching tasks and found age-related changes in the way emotional content was represented in WM. Specifically, older adults recalled fearful faces from WM as being less fearful than did younger adults, indicating an age-related attenuation in the representation of negative information in WM. Furthermore, older adults exhibited a positive interpretation bias whereby they were more likely to categorize low-intensity, fearful faces as being happy compared to younger adults. There were similarities between the patterns of results for the perceptual matching and WM tasks but the results were relatively weak in the perception task and did not reach statistical significance. Separate to the changes in emotional bias, we found a general age-related impairment, where older adults performed worse than younger adults in the WM and perceptual emotion-matching task for both happy and fearful faces.

By developing a novel task and analysis procedure, we revealed that the representation of emotional expressions in WM changes with age; older adults exhibited a systematic bias to remember fearful faces as less fearful than younger adults. There was no difference in bias for happy faces, suggesting that it is the representation of negative information in WM, and not positive information, that changes with age. Interestingly, the pattern of results was dissociable from a general decline in WM accuracy, since older adults showed worse performance in WM and in the emotion-matching task for both happy and fearful faces.

The age-related difference in bias for fearful faces was partly driven by more ambiguous expressions closer to neutral emotion. Low-valence fearful faces were sometimes mistakenly interpreted as happy faces. Exclusion of such miscategorization trials dampened some of the relevant statistics, partly by lowering statistical power, but did not affect the overall pattern of results showing a shift toward a positivity bias in older participants. The interaction between Age and Emotion-type became a marginal trend, but the affective bias reflected in the shift in the psychometric curve remained robust after exclusion of incorrect responses. Furthermore, inspecting the curves suggests that the age-related bias occurred not only for low-intensity ambiguous faces, but also extended to faces with medium and high fearful intensities. Overall, the findings suggest that the age-related difference in bias may partly reflect re-interpretation of ambiguous expressions, but is not confined to such a process, extending also to attenuating emotional content in stimuli with higher emotional valence.

To date, most studies that have explored age-related changes in emotional processing have used accuracy-based measures of bias, which gives a measure of preferential processing (e.g., attending more to positive than negative stimuli) but leaves open how the information was represented which lead to the behavioral effect. We note that although performance impairments were greater for fearful compared to happy faces, categorisation and memory performance are often better for happy faces (e.g. Calder et al., 2003), suggesting effects related to perceptual features. Thus our task was able to show how negative affective information in WM is attenuated with age, and that this was separate from age-related declines in WM.

Our task also enabled us to inspect age-related changes for interpreting ambiguous emotional expressions in WM. Older adults tended to judge low-intensity, ambiguous fearful faces as more happy than younger adults, suggestive of a positive interpretation bias in WM. Although participants were more likely to misinterpret low-intensity happy faces as fearful (c.f. Phillips et al., 1998), older adults were more likely to report low-intensity fearful faces as happy, reflecting a tendency to interpret ambiguous expressions from WM positively. These results are consistent with emotion-categorisation studies with ambiguous expressions (Bucks, Garner, Tarrant, Bradley, & Mogg, 2008; Kellough & Knight, 2012). Together, our findings indicate that older adults show an attenution of negative information in WM, and a positive intepretation bias when dealing with ambiguous information. Our results are consistent with the positivity effect in aging (Carstensen, Isaacowitz, & Charles, 1999; Mather & Carstensen, 2005) , but demonstrate that age-related differences can stem from multiple sources. With standard accuracy-based measures, it can be hard to determine why accuracy differences between positive and negative emotion conditions arise. New experimental paradigms and analysis methods designed to measure different types of emotional biases like those presented here could lead to deeper insights into group and individual differences in affective processing.

Age-related differences in the perceptual matching task somewhat resembled the WM results, but did not reach statistical significance. Our perceptual matching task was primarily designed to ensure older participants could perceive the task stimuli sufficiently well and were able to produce responses that reproduced emotional content with high levels of precision. The task worked well in this regard, showing high levels of accuracy. Interestingly, however, though not statistically significant, the pattern of results is suggestive that positivity biases may even operate when making purely perceptual judgements. Unfortunately, because of the purpose for which we designed the perceptual-matching task, the smaller number of trials may have precluded robust testing of this possibility. It will be interesting, therefore, for future studies to extend on the current findings to test for potential emotional biases in interpreting perceptual stimuli.

Three previous studies have reported that WM for emotional content is preserved in aging regardless of the valence (Hartley et al., 2015; Mammarella et al., 2013; Truong & Yang, 2014), but the way they tested WM was fundamentally different to our task. Mammarella et al. (2013) tested WM for emotional and neutral words, whereas we used faces. Semantic meaning may be more similar across age groups and which would lead to a similar meaning-based memory benefit for emotional words (also see Truong & Yang, 2014).

Hartley et al. (2015) used change-detection WM tasks with emotional faces, and found that older adults performed as well as younger adults in the emotional-expression task but were impaired in the identity task. However, in the expression change-detection task, participants only had to recall the expressions without needing to remember visual features, which may have encouraged use of emotional-expression labels. Furthermore, since they used an accuracy-based measure, it is unclear why there was a performance benefit. Another study using a judgment-based measure of performance found that older adults performed better on positive compared to negative images on a WM task, whereas younger adults showed the opposite pattern (Mikels et al., 2005). It should be noted that the task used in this study had participants judge whether the image encoded into WM was more or less emotionally intense than the subsequently presented ‘test’ item (which were images of different things), and accuracy was based on concordance with emotional intensity ratings from an independent group of younger adults. Finally, Bermudez & Souza (2017) used a serial presentation WM task with positive, neutral, and negative images, and found an interaction between valence and age, revealing that older adults showed poorer performance on negative images compared to positive and neutral images, consistent with the age-related positivity effect. In the current study, we showed that older adults had a deficit in both WM and emotion-matching tasks with a particular deficit for fearful faces, consistent with deficits in emotion recognition (Ruffman, Henry, Livingstone, & Phillips, 2008), and found age-related shifts in the affective content in WM unobtainable using accuracy measures alone.

Face stimuli in this study comprised images of young adults. Although a previous study found no own-age bias for recognizing emotional expressions in younger and older participant groups (Ebner & Johnson, 2009), it will be useful to extend the current findings using emotional faces of older adults. Another limitation of the current study was the focus on only fearful and happy emotional expressions. The precision WM method we introduce should prove informative in charting to what extent biases are introduced in other emotional expressions, such as anger and disgust.

Although previous studies have reported a relationship between measures of anxiety and performance with emotional stimuli (e.g. see Yiend, 2010), we did not find any reliable results to suggest this is the case for WM. It could be that we did not recruit participants with a large enough range of anxiety scores, or that our measures might correlate with depressed mood (for which we did not have a good range). It will be interesting for future studies to test participants with a larger range of mood scores (e.g., patients) to test whether there are biases in WM for emotional material linked to mood, and if this changes with age. Another interesting possibility for future work is to test the specificity of our age-related performance deficits to emotional stimuli. It would be interesting to test participants on both the emotion WM task and a comparable WM task with non-emotional features, such as faces morphed from male to female, to test if age-related deficits would be worse than or similar to WM for emotion-relevant features.

Our study employed a novel emotion WM task which captured age-related impairments in cognition and at the same time revealed positive changes in emotional bias in WM that come with normal aging. Our findings provide support to the positivity effect hypothesis in aging (Carstensen et al., 1999), revealing a more nuanced picture of the origin for this bias within WM. With our sensitive new approach, we were able to reveal multiple aspects of affective processing that undergo change in aging – including an attenuation of negative information and a tendency for positive interpretation in WM. In future work, tasks and response methods that include continual measures of accuracy as well as measures of bias will be able to further reveal behavioral patterns in aging and characterize the emotional biases across individuals in mood and other psychological disorders.

Author Contributions

R.M. Mok and A.C. Nobre conceived and designed the study. R.M. Mok and J.E. Hajonides van der Meulen performed testing and data collection. R.M. Mok and J.E. Hajonides van der Meulen performed data analysis under the supervision of A.C. Nobre. R.M. Mok and A.C. Nobre interpreted the findings and wrote the manuscript with input from E.A. Holmes. All authors approved the final version of the manuscript for submission.

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Supplementary Online Materials

Stimuli and Apparatus

For each person (identity) in the stimulus set, one photograph was selected from each emotion type (fear, happy, neutral) in the mouth-open configuration forming a set of 3 (see figure S1 and S2 for examples). Each photo was cropped using an elliptical mask (dimensions of rectangle: 506 x 650 pixels; dimensions of ellipse: 350 x 572 pixels). For cropping, images were loaded into Matlab and converted into grayscale. The elliptical mask was overlaid onto the photographs to create a black border and saved as images (see figure S1). These images were then loaded into Morpheus Photo Morpher. For each person in the face stimulus set, a set of faces morphed from neutral-to-fear and a set of images morphed from neutral-to-happy were produced. This resulted in 16 facial identities with two morphed emotion stimulus sets. Ten of the highest quality stimulus sets were selected for the main experiment (see figure S2 for examples of a set of high quality morphed happy and fearful expressions). The remaining six identities were selected for practice trials.

In the emotion WM task, faces were presented at the center of the screen and subtended 10° x 16.3°. In the emotion-matching task, faces were presented at the left and right side of the fixation cross on the horizontal meridian (centered at ~9.75° in lateral visual angle from fixation). In both tasks, the fixation cross was a plus sign ("+") at the center of the screen subtending ~1.5°, and stimuli were presented on a black background.

Eye movements were monitored on-line with an eye-tracker (EyeLink 1000, SR Research, Ontario, Canada) recording at 500 Hz.

The task was programmed and run in Matlab v.7.10 (MathWorks) using the Psychophysics Toolbox v.3.0 package (Brainard, 1997). The task was presented on an LCD screen with a spatial resolution of 1680 by 1200 pixels and a refresh rate of 60 Hz, placed ~67.5 cm from the participant.

Procedure

Participants first completed five self-report mood questionnaires on an iPad (Qualtrics online survey software; Qualtrics, Provo, UT), then proceeded to the main experimental task. The experimenter verbally explained each experimental task with a PowerPoint slide presentation, each of which was followed by practice trials. Participants were given one to two practice blocks of each task (10 trials per block). The practice tasks were the same as those in the main experiment, except that the facial identities were selected from the practice set. In the main experiment, all participants performed the emotional WM task followed by the emotional-expression matching task, with breaks in between.

Trial Numbers

After excluding trials with neutral (0% intensity) faces, there were 152 trials (76 per emotion-type condition) for the WM task, within which there were 16 trials per emotional intensity bin (12 trials for intensity bin 1, which excludes 0%). After removing misreported emotion trials, there were 72.8±.32 / 70.33±.60 (young/old) trials for the fearful face conditions and 67.1±.67 / 67.6±.67 (young/old) trials for the happy face conditions (out of 76 trials). Split into number of trials per emotional intensity bin, the mean number of trials per bin (young/old) were as follows: bin 1: 17.33±.37 / 17.45±.44, bin 2: 27.83±.34 / 26.37±.37, bin 3: 31.15±.15 / 30.67±.20, bin 4: 31.70±.09 / 31.57±.14, bin 5: 31.87±.05 / 31.86±.05 (note that bin 1 has 24 trials and others have 36 trials).

For the emotion-matching task, there were 38 trials (19 per emotion-type condition) after excluding trials with neutral faces, within which there were 4 trials per emotional intensity bin (3 trials for intensity bin 1, which did not include 0% emotional intensity). After removing misreported emotion trials, there were 18.30±.11 / 17.76±.21 (young/old) trials for the fearful face conditions and 18.48±.09 / 18.27±.12 (young/old) trials for the happy face conditions (out of 19 trials). Split into number of trials per emotional intensity bin, the mean number of trials per bin (young/old) were as follows: bin 1: 2.09±.14 / 1.86±.13, bin 2: 3.72±.07 / 3.20±.15, bin 3: 3.96±.03 / 4.00±.00, bin 4: 4.00±.00/ 4.00±.00, bin 5: 4.00±.00 / 3.98±.02 (note that bin 1 has 3 trials and the others have 4 trials).

Maximum response time trials

There were very few trials in which participants required the maximum response time (11s). Most participants did not have any of these trials, and the number of such trials was not significantly different between groups as reported below. Excluding these trials did not affect the results reported. The mean number of maximum response trials in the WM for fearful faces condition was *M*=.35, *SEM*=.15 (max=7) in the younger group and *M*=.51, *SEM*=.14 (max=4) in the older group (t(103)=-0.767, p=0.445, d=-0.15), and in WM for happy faces was *M*=.41, *SEM*=.12 (max=4) in the younger group and *M*=.33 , *SEM*=.13 (max=5) in the older group (t(99.3)=-1.43, p=0.15; d=-0.28). The mean number of maximum response trials in the emotion-matching task for fearful faces was *M*=.35, *SEM*=.08; (max=2) in the younger group and *M*=.53, *SEM*=.09 (max=3 trials) in the older group (t(100.4)=0.42, p=0.68, d=0.08), and for emotion-matching for the happy faces was *M*=.43, *SEM*=.10

(max=3) in the younger group and *M*=.45, *SEM*=.09; (max=3) in the older adults ($t(103)=-0.19$), $p=0.85$, $d=-0.04$).

Supplementary figures

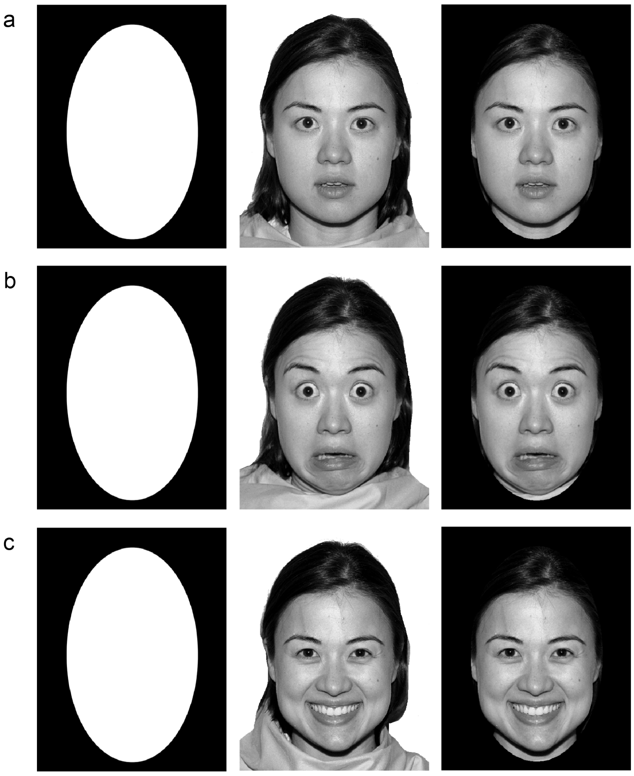

Figure S1. Cropping stimuli. An elliptical mask was laid over each photograph for (a) neutral (b) fearful and (c) happy faces. Faces presented are part of the NimStim stimulus set which are allowed for publication.

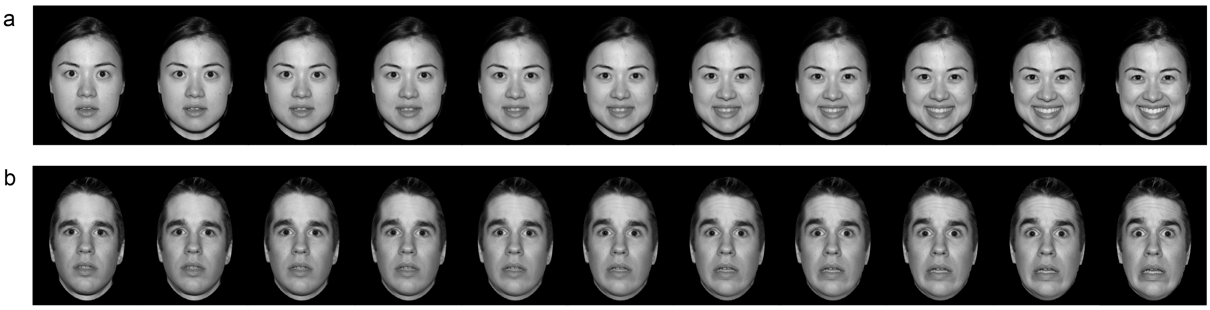

Figure S2. Examples of the full set of morphed images from 0 to 100% in 10% steps for a neutral-to-happy morph (a) and a neutral-to-fear morph (b). Faces are part of the NimStim stimulus set which are allowed for publication.

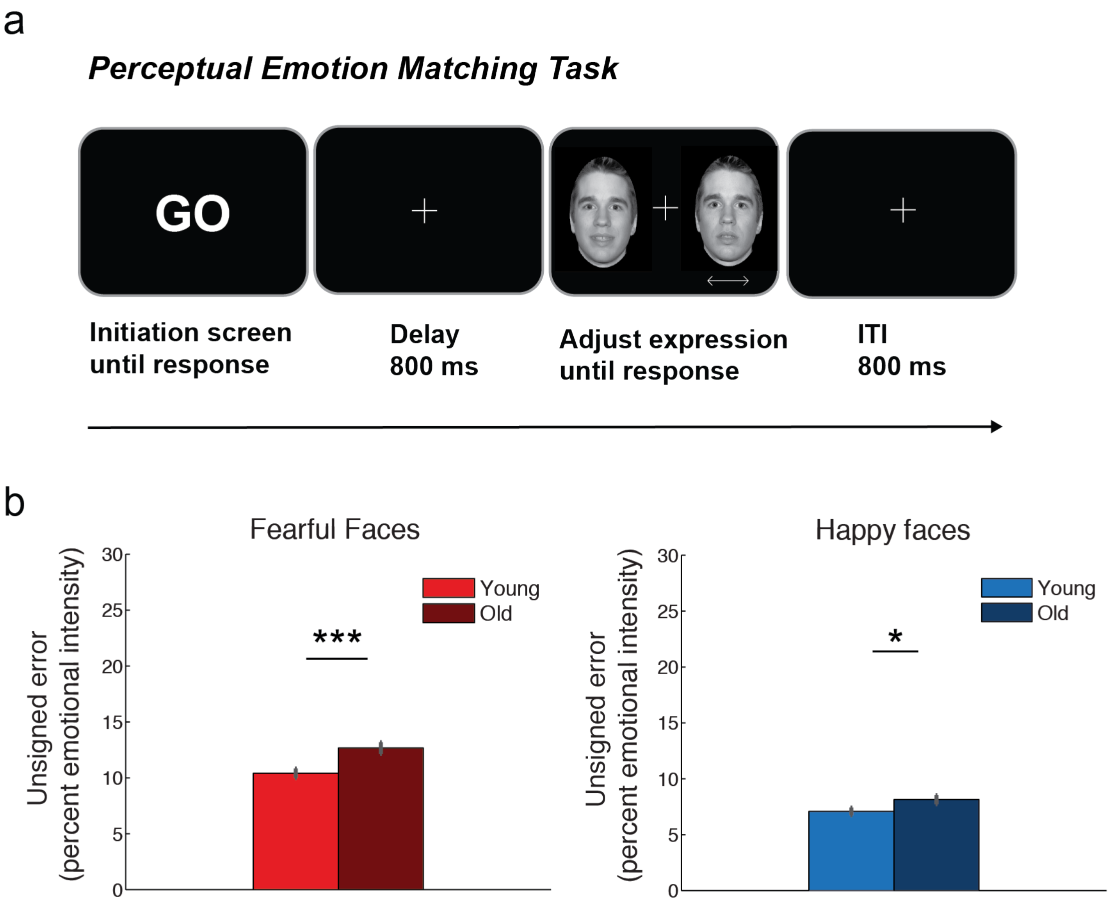

Figure S3. Emotion-matching task schematic and error results. In the perceptual emotion-matching task (a), participants initiated the trial with a mouse click, and were presented with an emotional face on the left and a neutral face on the right of the screen. Participants adjusted the emotional expression of the face on the right to match the emotion type and intensity of the face on the left using a trackball mouse. Emotion type was intermixed within blocks. Bar plots in (b) show emotion-matching error for fearful faces (left) in the young (light red) and old (dark red) groups and happy faces (right) in the young (light blue) and old (dark blue) participant groups. Error bars represent SEM *** p<.001, * p<.05. Faces presented are part of the NimStim stimulus set which are allowed for publication.

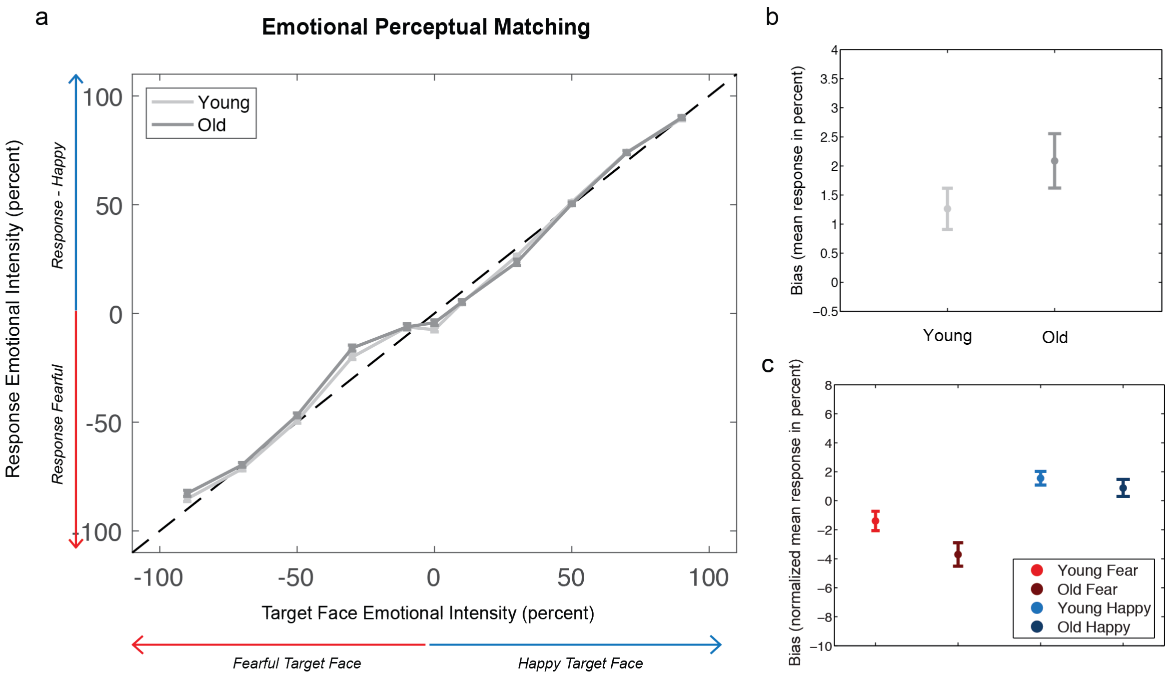

Figure S4. Emotional bias in perceptual-matching task. Participants' responses are plotted as a function of the target face emotion type and emotional intensity in (a), with negative values representing intensity values of fearful faces and positive values representing intensity values of happy faces. Responses are binned into five equal bins for fearful faces, five bins for happy faces and a 0% bin with only neutral faces. The bias is shown in (b), computed by taking the mean of each participant's raw psychometric curve. Bias for each of the emotion types separately in plot in (c). Conventions as in figure 2 in the main text.

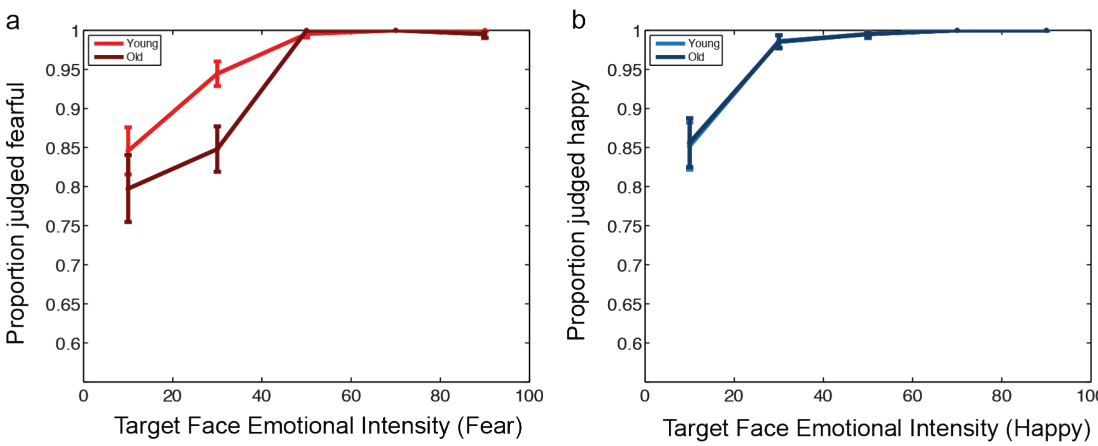

Figure S5. Proportion of trials correctly judged as fearful in the emotion-matching task are plotted for each emotional intensity bin from 1% to 80% in 20% steps in (a) and proportion of trials correctly judged as happy are plotted in (b) for younger and older participants.

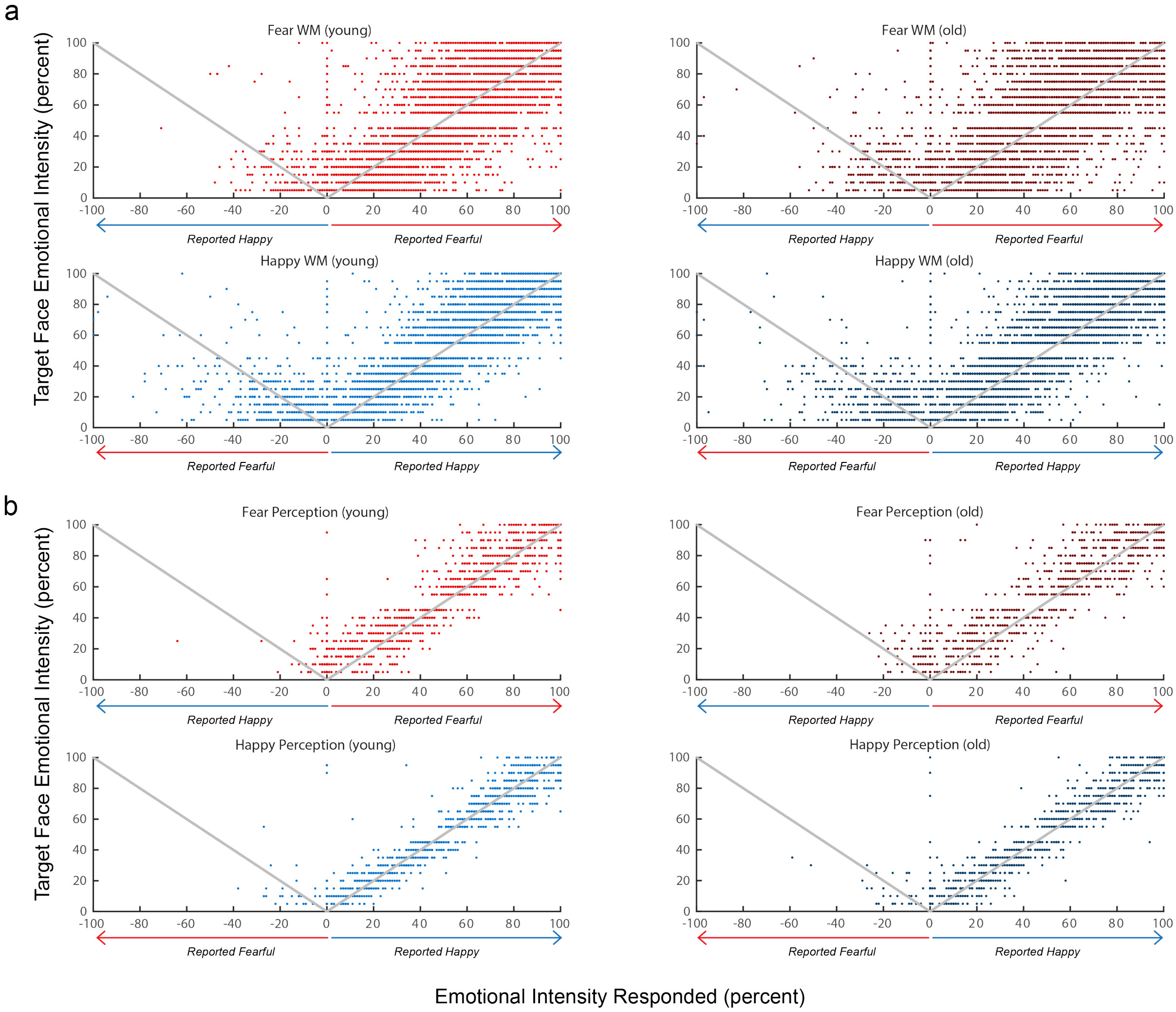

Figure S6. Scatterplots showing trials where participants correctly reported and misreported the emotion type for each Emotion and Intensity value condition. Scatter plots in (a) show target face emotional intensities plotted as a function of participant responses for emotional WM for fearful and happy faces, for young and older adults. Each point is an individual trial, and each scatter plot includes all trials in the specified condition in all participants within the age group presented. In all plots, the x-axis is-the reported emotional intensity, y-axis is the target emotional intensity value; positive values correspond to the target emotion type intensities, negative values correspond to the other emotion type intensities. Responses to the correct emotion type lie to the right of zero, and responses to incorrect emotion type lie to the left of zero (note that the x-axes denoting the fearful face and happy face responses are flipped for the different emotion type conditions). Correct responses would lie on the identity line (y=x) on the right of each plot. A 'mirrored' version of the identity line (y=-x) is plot on the left side for reference (e.g. if participants interpreted a 20% happy face to be 20% fearful, it would lie on this line). Scatterplots in (b) show target face emotional intensities plotted as a function of participant responses for emotional-expression matching. Conventions as in (a).