Psychology Press
Taylor & Francis Group

Negative emotional outcomes impair older adults' reversal learning

Kaoru Nashiro[1], Mara Mather[1], Marissa A. Gorlick[2], and Lin Nga[1]

[1]Davis School of Gerontology, University of Southern California, Los Angeles, CA, USA
[2]Department of Psychology, University of Texas, Austin, TX, USA

In a typical reversal-learning experiment, one learns stimulus–outcome contingencies that then switch without warning. For instance, participants might have to repeatedly choose between two faces, one of which yields points whereas the other does not, with a reversal at some point in which face yields points. The current study examined age differences in the effects of outcome type on reversal learning. In the first experiment, the participants' task was either to select the person who would be in a better mood or to select the person who would yield more points. Reversals in which face was the correct option occurred several times. Older adults did worse in blocks in which the correct response was to select the person who would not be angry than in blocks in which the correct response was to select the person who would smile. Younger adults did not show a difference by emotional valence. In the second study, the negative condition was switched to have the same format as the positive condition (to select who will be angry). Again, older adults did worse with negative than positive outcomes, whereas younger adults did not show a difference by emotional valence. A third experiment replicated the lack of valence effects in younger adults with a harder probabilistic reversal-learning task. In the first two experiments, older adults performed about as well as younger adults in the positive conditions but performed worse in the negative conditions. These findings suggest that negative emotional outcomes selectively impair older adults' reversal learning.

Keywords: Reversal learning; Aging; Emotion; Reward; Feedback.

Learning to update information in a rapidly changing environment is an important skill for social and behavioural adaptation. For example, the first few times you told a particular joke, your spouse might have laughed, but when you tell it once again, your spouse no longer laughs, and worse yet, frowns. Such feedback can influence future choices about whether to tell the joke

again. Laboratory reversal learning tasks tap the ability to switch behaviour based on these sorts of changing outcomes. In a typical reversal-learning experiment, one learns stimulus–reward contingencies (e.g., selecting a particular object yields a monetary reward). Once one has learned the initial association, a cue signals that the association is no longer valid (e.g., the object that once

1014

yielded the reward no longer does so) at which point one needs to change the response accordingly. Thus, reversal-learning tasks assess the ability to recognise changing contingencies, update associations and alter behaviour accordingly.

In general, reversal-learning performance is poorer among older adults than among younger adults. For instance, in one study, participants were shown several letters and asked to select the one that would yield the most points (Mell et al., 2005). Some letter selections tended to earn more points than others, but these contingencies reversed each time participants correctly chose the highest yielding letter for 6 to 8 successive trials in a row. Older adults gained fewer points and made more errors than did younger adults. This age-related deficit was not related to performance on tasks measuring other executive functions, suggesting that reversal learning taps different processes than standard measures of executive function. In another study, participants learned the associations between Asian symbols and colours, and correct answers were rewarded with monetary feedback (Weiler, Bellebaum, & Daum, 2008). Younger adults showed increased learning across three blocks but older adults did not improve across blocks.

Previous studies revealing age differences in reversal learning, however, did not take the salience of outcomes into account. Outcomes are here defined as consequences as a result of learning performance; for example, positive outcomes include money or praise received for correct responses. In the context of reversal learning, one has to keep track of previous outcomes in order to maximise subsequent performance; therefore, the salience of outcomes may play an important role in the overall rate of learning, and different types of outcomes may lead to different levels of performance. In this study, we focused on two types of outcomes: emotional and non-emotional outcomes. We defined emotional outcomes as those that have an intrinsic emotional content, such as happy faces. In contrast, we defined non-emotional outcomes as those that do not have an intrinsic emotional component, such as points, or whether someone is wearing eyeglasses. Previous

research suggests that the ability to detect and react to emotional stimuli remains stable in normal ageing (Leclerc & Kensinger, 2008; Mather & Knight, 2006) and both younger and older adults remember emotional stimuli better than neutral stimuli (Murphy & Isaacowitz, 2008). Given the fact that older adults have demonstrated relatively well-preserved attention and memory for emotional information, it seems possible that they show similar effects of emotion on reversal learning with emotional outcomes. Thus, in the present study, we examined whether emotionally salient outcomes would be more effective than non-emotional outcomes in older adults' reversal learning.

Beyond just the presence or absence of emotion in stimuli, it is important to consider the emotional valence of outcomes. To date, only a few studies have investigated the effects of valence of outcomes on reversal learning, and the findings are inconclusive. One study with younger adults found that participants made more errors when they learned switches to angry faces than to happy faces, and that the neural processes measured by event-related potentials (ERPs) was reduced for the former rather than the latter types of associative learning (Willis, Palermo, Burke, Atkinson & McArthur, 2010). However, another study with younger adults found that reversal learning activates the same region, namely the orbitofrontal cortex, regardless of the valence of outcomes to cue reversals or incorrect responses (Kringelbach & Rolls, 2003). Previous studies have found that older adults tend to favour positive and avoid negative information in their attention and memory (see Mather & Carstensen, 2005, for a review). For instance, studies have found that when a neutral picture or face is shown next to a negative or positive picture or face, older adults often spend a smaller proportion of their viewing time on the negative stimuli and a larger proportion on the positive stimuli than younger adults do (Isaacowitz, Allard, Murphy, & Schlangel, 2009; Isaacowitz, Wadlinger, Goren, & Wilson, 2006a, 2006b; Knight et al., 2007; Mather & Carstensen, 2003; Rosler et al., 2005). Likewise, when two speakers are on the screen and one is presenting a positive perspective and the other a

negative perspective, older adults show relatively less attention to the negative speaker than do younger adults (Fung, Isaacowitz, & Lu, 2010). Unlike younger adults, older adults' avoidance of negative and attraction to positive stimuli increases when they are induced into a negative mood, suggesting they use attention to help regulate mood (Isaacowitz, Toner, Goren, & Wilson, 2008).

Other studies show that older adults favour positive more or negative less in their memories than do younger adults (Charles, Mather, & Carstensen, 2003; Fung et al., 2010; Glisky & Marquine, 2009; Grühn, Scheibe, & Baltes, 2007; Ko, Lee, Yoon, Kwon, & Mather, 2010; Kwon, Scheibe, Samanez-Larkin, Tsai, & Carstensen, 2009; Langeslag & van Strien, 2009; Mather & Carstensen, 2003; Mather & Knight, 2005; Mather, Knight, & McCaffrey, 2005; Tomaszczyk, Fernandes, & MacLeod, 2008). However, such age-related positivity effects in attention and memory do not always show up (Comblain, D'Argembeau, Van der Linden, & Aldenhoff, 2004; Denburg, Buchanan, Tranel, & Adolphs, 2003; Fung et al., 2008; Grühn, Smith, & Baltes, 2005; Kensinger, Brierley, Medford, Growdon, & Corkin, 2002) and can even be reversed (Knight et al., 2007; Mather & Knight, 2005). One factor that seems to be important is whether older adults have cognitive control resources available to devote to the emotion-related task, as prior evidence suggests that the positivity effect emerges as a result of effortful cognitive control among older adults and when this effort is not readily available, they show no positivity effect (Isaacowitz, Toner, & Neupert, 2009; Knight et al., 2007; Mather & Knight, 2005; Petrican, Moscovitch, & Schimmack, 2008). Thus, in the present study, to see how emotion would affect older adults' reversal learning, we used relatively simple reversal-learning tasks that would not place high demands on cognitive resources.

Neuroimaging studies have also found differential effects of valence on young and older adults' reward-based learning. A recent study investigating brain activity during anticipation of gain and loss revealed that younger and older adults showed similar striatal and insular activation during anticipation of gains (positive outcomes), but older adults showed less activation than younger adults during anticipation of losses (negative outcomes; Samanez-Larkin et al., 2007). Another reward-based learning experiment revealed that not all older adults were impaired in decision making, and a subset of (unimpaired) older adults performed as well as younger adults on a reward-based gambling task (Denburg, Tranel, & Bechara, 2004). Intriguingly, in a subsequent experiment (Denburg, Recknor, Bechara, & Tranel, 2006), the unimpaired older group generated more skin conductance responses during anticipation of gain than that of losses, whereas younger adults showed the opposite pattern. It is important to note that the majority of older adults in this study were in the unimpaired group, and that this group of older adults appears to be more attuned to positive than negative information. These findings together with older adults' positivity effect in attention and memory discussed earlier suggest the possibility that older adults learn more effectively when outcomes are positive than when they are negative.

In summary, the current study had two objectives. First, we tested the hypothesis that older adults learn more effectively given emotional rather than non-emotional outcomes in reversal learning. Second, we tested the prediction that older adults learn more effectively given positive than negative outcomes in reversal learning. Three experiments were conducted, each of which had three different outcomes in three different conditions: (1) positive-emotion; (2) negative-emotion; and (3) non-emotion conditions. In order to examine the effect of emotional versus non-emotional outcomes on reversal learning, performance in Conditions 1 and 2 (positive and negative emotional outcomes) were combined and contrasted with that in Condition 3 (non-emotional outcomes). Furthermore, learning rates in Conditions 1 and 2 were compared to address our question about differences in positive versus negative outcome conditions. Age differences were found only in the negative conditions, which supported our second hypothesis.
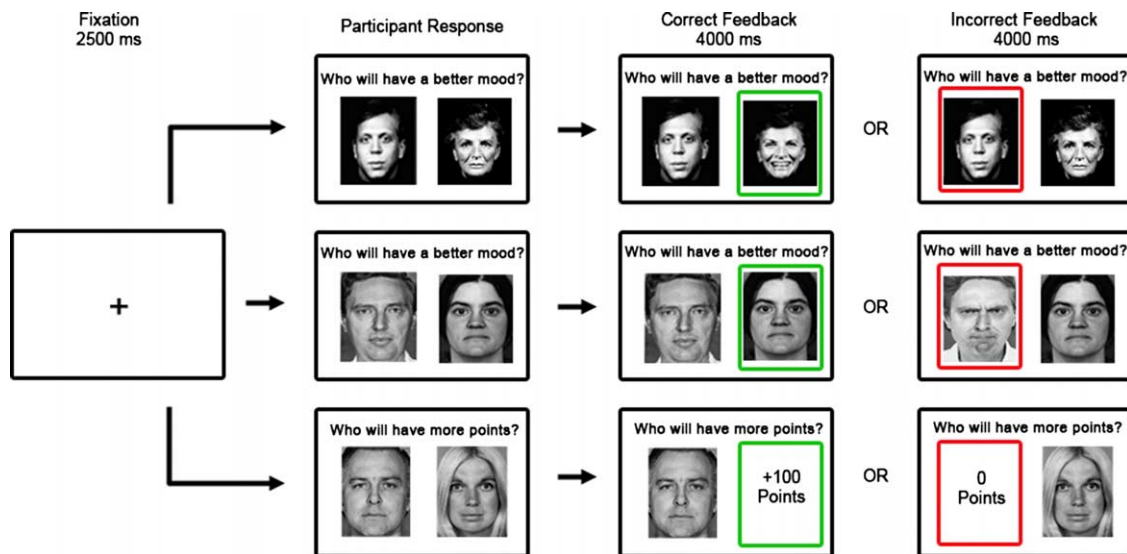
EXPERIMENT 1

Method

Participants. We recruited 18 undergraduates ($M_{age} = 20.72$, 3 males, 15 females, age range 18–25) and 17 older adults over 65 years old from various retirement communities ($M_{age} = 72.67$, 6 males, 12 females, age range 62–83). Due to the different gender ratio among the younger and older participants, we included gender as a covariate in all analyses. There was no significant effect of gender in any of the analyses; hence, we will not further discuss gender as a factor. The younger participants received course credit for their undergraduate psychology classes, and older participants received monetary compensation for their participation. The experiments were conducted either at participants' homes or in the laboratory.

Materials. Experiment 1 was programmed using Macromedia Authorware software. The grey-scale face stimuli were gathered from the *Pictures of Facial Affect* database (Ekman & Friesen, 1976). Eight individuals' faces were used, which were divided into four pairs of two faces. One pair was used in the practice trials, and the three other pairs were used in the positive, negative, and non-emotion conditions of the main experiment. Thus, for each participant, the same two faces were used throughout each condition. In each condition, one face was male and one was female to make it easier to discriminate between the two options. Each face used in the main experiment had neutral, happy and angry versions, and all of the faces were presented at 288×375 pixels.

Procedure. Participants first filled out the informed consent, demographic information, and rated their current mood using the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988). Each trial began with a fixation cross presented for 2500 ms followed by two neutral faces. Face stimuli were randomly assigned to the left or right side of the screen on each trial. As soon as

participants selected one face by pressing a key corresponding to the left or right side of the screen, feedback was presented for 4000 ms. Correct choices were framed in bright green and showed a happy face for the positive condition, a neutral face for the negative condition, and " + 100 Points" for the non-emotion condition. Incorrect choices were framed in dark green and showed a neutral face for the positive condition, an angry face for the negative condition, and "0 Points" for the non-emotion condition. Before the main experiment began, participants completed a one-reversal practice block with the task of identifying the person who had a house key. The rest of the rules were identical to the main experiment. The main experiment consisted of three blocks of tasks: positive, negative, and non-emotion conditions (see Figure 1), with block order randomised across the participants. In the emotion conditions (positive and negative), participants were presented with two neutral faces concealing their emotions and had to select the person who would be in a better mood. The prompt, "Who will have a better mood?" appeared above the faces. In the positive condition, the correct person smiled, and the incorrect person remained neutral. In the negative condition, the correct person remained neutral, and the incorrect person showed an angry expression. In the non-emotion condition, participants were presented with two neutral faces hiding different numerical values assigned to them, and they had to choose the person who had the highest assigned value. The prompt, "Who will have more points?" appeared above the faces. The feedback was given by showing the assigned value carried by the chosen person (either 0 or 100 points). Across all conditions, participants were asked to change their answers as soon as they noticed the switch. After the participant made five consecutive correct responses, the correct face switched. Each condition comprised two rule reversals and ended when participants reached the learning criterion of five consecutive correct responses after the last rule reversal. The

Figure 1. *Procedure of Experiment 1. The positive (top), negative (middle) or non-emotion conditions (bottom) were assigned to the subject in a random order. The trial began with a fixation cross presented for 2500 ms, and two people with neutral face expressions were presented to the subject. The subject had to select one of the people by pressing a key, and feedback was presented for 4000 ms. In the positive condition, the correct person smiled, and the incorrect person remained neutral. In the negative condition, the correct person remained neutral, and the incorrect person showed an angry expression. In the non-emotion condition, the correct person showed 100 points, and the incorrect person showed 0 points. Across conditions, the task for the subject was to keep track of the correct face because it switched mid-game (after five consecutive correct trials, which was unknown to the subject).*

number of trials varied across participants ($M = 18$).

Results

Throughout the paper, we report partial eta squared (η_p^2) as a measure of effect size.

Current emotions. Independent samples t-tests indicated that there were significant differences between the younger and older groups in reported positive affect ($M_{young} = 24.22 \pm 5.33$; $M_{old} = 36.71 \pm 5.73$), $t(33) = -6.68$, $p < .001$, and in reported negative affect ($M_{young} = 15.78 \pm 6.07$; $M_{old} = 11.06 \pm 2.61$), $t(33) = 2.95$, $p = .006$. We included current emotions as a covariate in our initial analyses; however, there was no significant effect of current emotions in any of the analyses and their inclusion as covariates did not affect the pattern of other significant results. Hence, the following analyses were conducted without the covariates.

Reversal learning: Emotion vs. non-emotion conditions. We used the absolute number of errors, instead of the proportion of errors, as the dependent variable. Computing errors as a proportion of total trials would assume that each trial is equally easy to get correct, which may not be the case. For instance, consider a participant with correct responses in trials 2–5 after a reversal but then an error on trial 6. That participant would then have to complete a new sequence of correct responses before a reversal would occur, leading to more trials—but those additional trials may be easier to get correct given the greater experience with those particular face–outcome contingencies. The range of errors made by each age group is divided into three categories and shown in Table 2. The errors made in the first trial of each condition were excluded, as those were guessing errors and were not due to failure of learning previous associations. The positive and negative conditions were combined as an emotion condition, and the total number of errors averaged across

the two conditions was contrasted with the total number of errors in the non-emotional condition. A 2 (Group) × 2 (Conditions: emotion and non-emotion) repeated-measures analysis of variance (ANOVA) revealed a main effect of Group ($M_{young} = 1.82$, $SE = 0.25$; $M_{old} = 2.79$, $SE = 0.26$), $F(1, 33) = 7.21$ $MSE = 2.30$, $p = .001$, $\eta_p^2 = .18$. There was no main effect of Condition, $F(1, 33) = 2.56$, $p = .12$, $\eta_p^2 = .07$, and no interaction between Group and Condition, $F(1, 33) = 0.66$, $p = .42$, $\eta_p^2 = .02$ (see Table 1 for all means and standard errors).

Reversal learning: Positive vs. negative conditions. Errors were summed for the positive and negative conditions for each participant, excluding the errors made in the first trial of each condition. A 2 (Group) × 2 (Conditions: positive and negative) repeated-measures ANOVA revealed that overall, younger adults performed better than older adults ($M_{young} = 1.69$, $SE = 0.22$; $M_{old} = 2.41$, $SE = 0.23$), $F(1, 33) = 5.18$, $MSE = 1.74$, $p = .030$, $\eta_p^2 = .14$. There was a main effect of Condition ($M_{positive} = 1.78$, $SE = 0.14$; $M_{negative} = 2.33$, $SE = 0.24$), $F(1, 33) = 5.44$, $MSE = 1.00$, $p = .026$, $\eta_p^2 = .14$. We also found an interaction between Group and Condition, $F(1, 33) = 4.41$, $MSE = 1.00$, $p = .044$, $\eta_p^2 = .12$ (see Table 1 for all means and standard errors and Table 2 for the number of errors in three ranges); older adults made more errors in the negative than the positive conditions, $F(1, 16) = 6.23$, $MSE = 1.53$, $p = .024$, $\eta_p^2 = .28$, but younger adults did not show such a difference, $F(1, 17) = 0.06$, $MSE = 0.50$, $p = .816$, $\eta_p^2 = .003$. Independent samples *t*-tests comparing younger and older adults' performance in each of the two conditions revealed that older adults made more errors than younger adults in the negative condition, $t(33) = -2.50$, $p = .018$, but not in the positive condition, $t(33) = -0.79$, $p = .438$.

Reversal learning: All conditions. A 2 (Group: younger, older) × 3 (Conditions: positive, negative, non-emotion) repeated-measures ANOVA revealed a main effect of Group, $F(1, 33) = 8.01$, $MSE = 2.59$, $p = .008$, $\eta_p^2 = .20$, suggesting that younger adults performed better than older adults. We found a main effect of Condition, $F(2, 66) = 3.42$, $MSE = 1.67$, $p = .039$, $\eta_p^2 = .09$; participants across groups performed better in the positive than negative conditions, $t(34) = 2.17$, $p = .037$, and in the positive than the non-emotion conditions $t(34) = -2.43$, $p = .021$. The interaction between Group and Condition did not achieve significance when all three conditions were included, $F(2, 66) = 1.78$, $MSE = 1.67$, $p = .177$, $\eta_p^2 = .05$.

Discussion

Overall, older adults made significantly more errors than did younger adults, consistent with age-related decline in reversal learning. When considered together, emotional outcomes did not affect older adults differently from younger adults; however, age differences emerged when the positive and negative conditions were considered separately. Older adults learned about reversals as quickly as younger adults in the positive condition, whereas they learned at a slower rate than younger adults in the negative condition. It is

Table 1. *The average total number of errors in each condition in Experiment 1, 2 and 3*

| Condition | Experiment 1 | | Experiment 2 | | Experiment 3 |
	Younger (n = 18)	*Older (n = 17)*	*Younger (n = 20)*	*Older (n = 20)*	*Younger (n = 30)*
Non-emotion	1.94 (0.42)	3.18 (0.43)	2.15 (0.12)	2.35 (0.12)	27.53 (1.00)
Emotion-overall	1.69 (0.22)	2.41 (0.23)	2.03 (0.13)	2.50 (0.13)	28.87 (1.14)
Positive	1.67 (0.19)	1.88 (0.20)	2.05 (0.09)	2.25 (0.09)	28.87 (1.15)
Negative	1.72 (0.34)	2.94 (0.35)	2.00 (0.18)	2.75 (0.18)	28.87 (1.44)

Note: Standard errors are in parentheses.

Table 2. *The number of participants who made errors within each range (0–2 = between 0 and 2, 3–5 = between 3 and 5, 6 + = 6 and greater) in each condition in Experiments 1 and 2*

| | Experiment 1 | | Experiment 2 | |
| | Younger (n = 18) | Older (n = 17) | Younger (n = 20) | Older (n = 20) |
Condition				
Non-emotional				
0–2	14	10	16	14
3–5	4	4	4	6
6 +	0	3	0	0
Positive				
0–2	15	16	20	16
3–5	3	1	0	4
6 +	0	0	0	0
Negative				
0–2	16	9	19	11
3–5	2	5	1	8
6 +	0	3	0	1

Note: The total number of errors in each condition is divided into three categories. The first category ranges from 0 to 2. Participants were expected to make an error immediately after each of the two reversals, as they were not explicitly informed when reversals would occur. Some participants, however, predicted the timing of reversals and made fewer than two errors. In any case, making up to two errors was expected in order to notice a change in stimulus–outcome contingencies. The second category ranges from 3 to 5, which is more than the expected number of errors but not exceedingly so. The last category is 6 and greater; a few participants who made a large numbers of errors fell into this category. The maximum number of errors was 10 in Experiment 1 and 6 in Experiment 2.

possible, however, that older adults' performance in the negative condition was due to the fact that the task was harder in the negative than the positive condition. It might have been more difficult for older adults to choose the happiest person between angry and neutral faces in the negative condition than selecting the happiest person between neutral and happy faces in the positive condition. Furthermore, the fact that both groups showed the poorest performance in the non-emotion condition could be due to the fact that the task in the non-emotion condition was the most difficult one of the three conditions because it involved a numerical outcome. In order to rule out these possibilities, we equated the

structure of the question and outcome format across the three conditions in the next experiment. Another issue with Experiment 1 was a possible ceiling effect for younger adults. Some younger adults and a few older adults predicted when the reversal occurred without being informed (there were two rule reversals but some participants made fewer than two errors, indicating that they predicted when the reversals would occur). To make the timing of reversals less predictable, we changed the learning criteria from five consecutive correct answers in Experiment 1 to five to seven consecutive correct responses in Experiment 2.

EXPERIMENT 2

Method

Participants. We recruited 20 undergraduates ($M_{age} = 19.55$, 2 males, 18 females, age range 18–24), and 20 older adults over 65 years old from various retirement communities ($M_{age} = 81.06$, 6 males, 14 females, age range 69–93). We included gender as a covariate in all analyses but found no significant effect of gender in any of the analyses. The younger participants received course credit, and older participants received monetary compensation for their participation. The experiments were conducted either at participants' homes or in the laboratory.

Materials. Experiment 2 was programmed using Macromedia Flash Professional 8. The colour face stimuli were gathered from the NimStim set of facial expressions (Tottenham et al., 2009). Eight individuals' faces were used, which were divided into four pairs of two faces. One pair was used in the practice trials, and the three other pairs were randomly assigned to the positive, negative, and non-emotional conditions. Additional images were created, using Adobe Photoshop 9.0.2 graphics program to impose images of a baseball cap on the two neutral faces used in the practice trials and to add eyeglasses to the six neutral faces used in the main experiment. All faces used in the practice trials had neutral and baseball-cap ver-

sions, and all faces for the main experiment had neutral, happy, angry, and eyeglasses versions. In each condition, one face was male and one was female to make it easier to discriminate between the two options. All of the faces were presented at 500×625 pixels.

Procedure. Participants first filled out the informed consent, demographic information, and the PANAS. Each trial began with a fixation cross presented for 3000 ms followed by two neutral faces. The face stimuli for each task were randomly assigned to conditions across participants and to side of the screen on each trial. Participants pressed a right or left key to select the corresponding face. After their response, feedback was presented for 3000 ms. Correct choices were framed in green and either gained an emotional expression or glasses, depending on the condition. Incorrect choices were framed in red and the face did not change. Before the main experiment began, participants completed a shorter one-reversal practice block involving identifying who would put on a baseball cap. The rest of the rules were identical to the main experiment. The main experiment consisted of positive, negative, and non-emotion conditions, the order of which was randomised across the participants. In order to equate task difficulty across the conditions, we simplified the questions and changed outcome format while participants still had to keep track of emotional versus non-emotional information in order to meet the learning criterion. In the emotion conditions (positive and negative), the participant had to select the person who would show an emotional expression (happy or angry). In the non-emotional condition, participants had to select the person who would wear eyeglasses. Before each block began, participants were prompted with "Who will be happy?" for the positive condition, with "Who will be angry?" for the negative condition, and with "Who will put on glasses?" for the non-emotional condition (see Figure 2). In all three conditions, correct responses led to an emotional change in the face (happy, angry) or the face with eyeglasses, while incorrect choices led to the neutral face with no change in the face. Across conditions, participants

were instructed to keep track of the correct face because it would switch mid-game. Participants were asked to change their answers as soon as they noticed the switch. After the participant made between five and seven consecutive correct responses, the correct face changed. Each condition comprised two rule reversals and ended when participants reached the learning criteria after the last rule reversal. The number of trials varied across participants ($M = 21$).

Results

Current emotions. There was a significant difference between the younger and older groups in reported positive affect ($M_{young} = 27.85 \pm 5.54$; $M_{old} = 35.30 \pm 7.77$), $t(38) = -3.49$, $p = .001$, but not in reported negative affect ($M_{young} = 13.45 \pm 4.38$; $M_{old} = 11.75 \pm 3.78$), $t(38) = 1.31$, $p = .197$. Thus, we included positive affect as a covariate in our initial analyses. There was no significant effect of positive affect in any of the analyses and its inclusion as a covariate did not affect the pattern of other significant results; hence, the following analyses were conducted without this covariate.

Reversal learning: Emotion vs. non-emotion conditions. Errors were calculated in the same way as in Experiment 1. The range of errors made by each age group was divided into three categories and is shown in Table 2. A 2 (Group) $\times$ 2 (Conditions: emotion and non-emotion) repeated-measures ANOVA revealed a main effect of Group ($M_{young} = 2.09$, $SE = 0.10$; $M_{old} = 2.43$, $SE = 0.10$), $F(1, 38) = 6.25$, $MSE = 0.36$, $p = .017$, $\eta_p^2 = .14$. There was no main effect of Condition, $F(1, 38) = 0.01$, $p = .914$, $\eta_p^2 = .00$, and no interaction between Group and Condition, $F(1, 38) = 1.44$, $p = .238$, $\eta_p^2 = .04$ (see Table 1).

Reversal learning: Positive vs. negative conditions. A 2 (Group) $\times$ 2 (Conditions: positive and negative) repeated-measures ANOVA revealed that overall, younger adults performed better than older adults ($M_{young} = 2.03$, $SE = 0.13$; $M_{old} = 2.50$, $SE = 0.13$), $F(1, 38) = 6.73$,
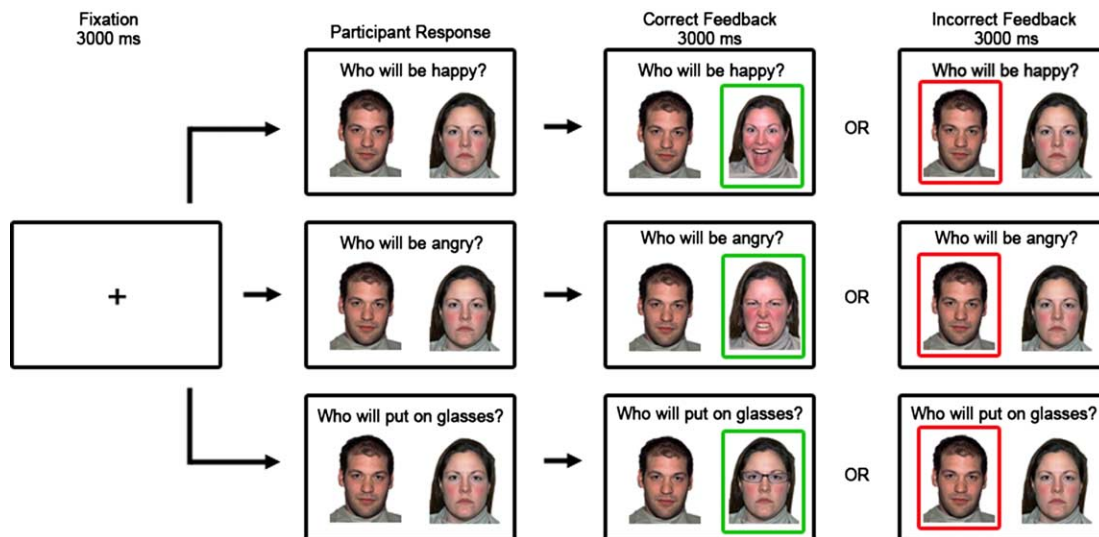
Figure 2. *Procedure of Experiment 2. The positive (top), negative (middle) or non-emotion conditions (bottom) were assigned to the subject in a random order. The trial began with a fixation cross presented for 3000 ms, and two people with neutral face expressions were presented to the subject. The subject had to select one of the people by pressing a key, and feedback was presented for 3000 ms. In the positive condition, the correct person smiled, and the incorrect person remained neutral. In the negative condition, the correct person showed an angry expression, and incorrect person remained neutral. In the non-emotion condition, the correct person wore eyeglasses, and the incorrect person remained neutral. Across conditions, the task for the subject was to keep track of the correct face because it switched mid-game (after between five and seven consecutive correct trials, which was unknown to the subject).*

$MSE = 0.67$, $p = .013$, $\eta_p^2 = .15$. We found a main effect of Condition ($M_{positive} = 2.15$, $SE = 0.07$; $M_{negative} = 2.38$, $SE = 0.13$), $F(1, 38) = 5.52$, $MSE = 0.18$, $p = .024$, $\eta_p^2 = .13$. Moreover, there was an interaction between Group and Condition, $F(1, 38) = 8.24$, $MSE = 0.18$, $p = .007$, $\eta_p^2 = .18$ (see Tables 1 and 2). Older adults made more errors in the negative than the positive conditions, $F(1, 19) = 8.64$, $MSE = 0.29$, $p = .008$, $\eta_p^2 = .31$, but younger adults did not show such a difference, $F(1, 19) = 0.32$, $MSE = 0.08$, $p = .577$, $\eta_p^2 = .02$. T-tests comparing younger and older adults' performance in each of the two conditions revealed that older adults made more errors than younger adults in the negative condition, $t(38) = -2.88$, $p = .006$, but not in the positive condition, $t(38) = -1.51$, $p = .140$.

Reversal learning: All conditions. A 2 (Group) × 3 (Conditions: positive, negative, non-emotion) repeated-measures ANOVA revealed a main effect of Group, $F(1, 38) = 7.21$, $MSE = 0.61$,

$p = .011$, $\eta_p^2 = .16$. There was no main effect of Condition, $F(2, 76) = 1.90$, $MSE = 0.27$, $p = .156$, $\eta_p^2 = .05$. However, there was a significant interaction between Group and Condition, $F(2, 76) = 3.78$, $MSE = 0.27$, $p = .027$, $\eta_p^2 = .09$, suggesting that the effects of conditions (valence) on reversal learning differed between younger and older adults. As reported above, the group by condition interaction was driven by the fact that older adults made more errors in the negative than the positive conditions, whereas younger adults did not show such a difference.

Discussion

As in Experiment 1, when the two emotion conditions were combined, neither group differed in learning rates for emotion versus non-emotion conditions, suggesting that emotional feedback outcomes do not benefit either group. However, also as in Experiment 1, when positive and negative outcome conditions were compared, age differ-

ences emerged. Even though the task structure was equated across the three conditions, older adults still made more errors than younger adults in the negative condition (and not in the positive condition). Moreover, within-group comparisons revealed that older adults made more errors in the negative than the positive conditions, whereas younger adults did not show a difference in the negative versus positive conditions. One critical limitation in both Experiments 1 and 2 was a possible ceiling effect in younger adults. Although we attempted to make the reversals less predictable by varying the learning criteria (five to seven consecutive correct responses) in Experiment 2, younger adults' performance was still near ceiling. To address this issue, we conducted the next experiment.

EXPERIMENT 3

The objective of Experiment 3 was to make the task harder to see if younger adults would still show no effect of the outcome valence, or if an effect would emerge when they were no longer near ceiling in their performance. We increased task difficulty by using a probabilistic reversal-learning task. Older adults were not included in this experiment, as the objective was to see if younger adults would show an effect of valence when not at ceiling in their performance. For younger adults, task difficulty and the relative availability of cognitive resources is not hypothesised to matter for the relative influence of positive versus negative outcomes. However, as discussed in the introduction increasing the cognitive load required by the task might change the effects of valence on reversal learning among older adults. The interaction between valence and task difficulty for older adults would be an important but different question from the current experiment.

Method

Participants. Thirty undergraduates ($M_{age} = 20.63$, 11 males, 19 females, age range 18–26) participated in the study. We included gender as a covariate in all analyses; however, there were no

significant effects of gender. The participants received course credit and the experiments were conducted in the laboratory.

Materials. Experiment 3 was programmed using Matlab 7.9 and the Psychophysics Toolbox Version 3 (Brainard, 1997; Pelli, 1997). The face stimuli were colour images obtained from the FACES database developed at the Max Planck Institute for Human Development (Ebner, Riediger, & Lindenberger, 2010), which included young, middle-aged and older adults' female and male faces. Ten individuals' faces were used, which were divided into five pairs of two faces. Two pairs were used in the practice trials, and the three other pairs were used in the positive, negative, and non-emotion conditions of the main experiment. Additional images were created, using Adobe Photoshop 9.0.2 graphics program to impose images of a baseball cap on the two neutral faces used in the practice trials and to add eyeglasses to the six neutral faces used in the main experiment. For the practice trials, two faces had neutral and baseball-cap versions and two other faces had neutral and sad versions. All six faces used in the main experiment had neutral, happy, angry, and eyeglasses versions. Within each condition, the two faces in a pair were from the same age and gender group in order to make it harder to discriminate between the two options. All of the faces were presented at 480 × 555 pixels or 430 × 502 pixels on a 15-inch MacBook Pro and a 13-inch HP Pavilion dv6500, respectively.

Procedure. Participants first filled out the informed consent, demographic information, and the PANAS. Each trial began with two neutral faces presented on the screen on a white background. While each participant saw a pair of faces from each age group (young, middle-aged, older faces) across conditions, it was counterbalanced across participants whether the participant would see two pairs of male faces and a pair of female faces or vice versa. The face stimuli for each task were randomly assigned between conditions and were randomly assigned to the left or right side of the screen on each trial. Participants selected one

face by pressing a key corresponding to the left or right side of the screen. After their response, feedback was presented for 1000 ms on a grey background (when the face did not change, the grey background indicated a response was made) followed by a fixation cross presented for 2000 ms. Before the main experiment began, participants practised the task twice. First, they were instructed to find the person who would most likely wear a hat and to keep track of the correct face because it would switch occasionally throughout the game. Participants were informed that the person who was correct would appear wearing a hat, when selected, a majority of the time while sometimes selecting this person may lead to no change in either faces. Before the practice began, participants were prompted with the question, "Who is most likely wearing a hat?" After practising this condition, participants practised a second time but now were prompted with, "Who is most likely sad?" After the two practice blocks, all participants completed three conditions (positive, negative, and non-emotion) and were instructed that the same rules as the practice blocks applied. The order of conditions was randomised across the participants. In the emotion conditions (positive and negative), the participant had to keep track of the person who would most likely show an emotional expression (either happy or angry). In the non-emotion condition, participants had to keep track of the person most likely wearing eyeglasses. Before each block began, participants were prompted with, "Who is most likely happy?" for the positive condition, with, "Who is most likely angry?" for the negative condition, and with, "Who is most likely wearing glasses?" for the non-emotion condition. Across all conditions, participants were asked to change their answers as soon as they noticed a switch. After the participant reached the learning criterion of six to ten non-consecutive correct responses (the criterion was randomised independently for each block), the correct face changed. Each experimental block comprised nine rule reversals and ended when participants reached the learning criterion after the last rule reversal. Most times, correct choices led to an emotional change in the

face or the face with glasses, depending on the condition, but correct responses occasionally led to no change in the face (the face remained neutral despite the fact that the answer was correct). The change : no change ratio for each block was 80 : 20. Correct responses in the trials immediately before and after the reversal always led to a change in the face. Between each reversal, three or fewer of the correct responses by the participant led to neutral faces (i.e., no change in facial expression). The sequence in which these no-feedback trials occurred was randomly generated by the computer. Incorrect choices always led to the neutral face with no change in the face. The number of trials varied across participants ($M = 110$).

Results

Current emotions. The means of reported positive affect and negative affect among younger participates were 27.43 ($SD = 7.21$) and 13.63 ($SD = 3.56$) respectively.

Reversal learning: Emotion vs. non-emotion conditions. The total number of errors was calculated for each participant for each condition. A one-way ANOVA was conducted to test the difference in the total number of errors between the emotion and non-emotion conditions. We found no significant difference between the two conditions, $F(1, 29) = 1.37$, $MSE = 19.48$, $p = .251$, $\eta_p^2 = .045$, suggesting that younger adults learned at about the same rate in the two conditions (see Table 1).

Reversal learning: Positive vs. negative conditions. A one-way ANOVA was conducted to test the difference in the total number of errors between the positive and negative conditions. There was no significant difference between the two conditions, $F(1, 29) = 0.00$, $MSE = 23.24$, $p = 1.00$, $\eta_p^2 = .000$, suggesting that younger adults learned at about the same rate in the two conditions (see Table 1). In addition, there was no significant effect of order of the conditions ($p = .403$).

Discussion

We attempted to address the issue of possible ceiling effects in younger adults observed in Experiments 1 and 2. To achieve this goal, we increased task difficulty by using a probabilistic reversal-learning task. Consistent with the results in Experiments 1 and 2, younger adults did not show a significant effect of the outcome valence and the observed effect size for valence was quite small—in this case, near zero. It is important to note, however, that the non-significant valence effects do not necessarily indicate that there are not such effects.

GENERAL DISCUSSION

Consistent with previous findings, we observed age-related declines in reversal learning; overall, older adults made significantly more errors than did younger adults. However, the critical question was whether types of outcomes (emotional vs. non-emotional) would enhance or impair older adults' reversal learning. Our results suggest that whether outcomes are intrinsically emotional or not was not enough to explain age-related differences in reversal learning. Instead, a critical factor appears to be the emotional valence of outcomes. The first two experiments showed that older adults performed as well as younger adults in the positive conditions but performed worse in the negative conditions. Furthermore, within-group comparisons suggested that older, but not younger, adults made more errors in the negative than positive conditions. In Experiment 2, we equated a level of task difficulty and procedures across conditions so that the main difference between conditions was the emotional valence of outcomes. Importantly, in this experiment, the cue to signal one's answer was incorrect was neutral faces across all conditions; thus, the difference in performance could be attributed to the type of correct outcome. The fact that age differences emerged in the negative but not in positive conditions suggests that having to keep track of negative information interferes with effective reversal learning among older adults. On the other hand, older adults performed similarly to younger adults when there were positive outcomes. Furthermore, the lack of valence-dependent reversal learning among younger adults suggests that they are attuned to both positive and negative information whereas older adults seem to learn more effectively in the absence of negative contexts. Differential effects of valence on cognition between the two age groups was observed in prior studies of attention and memory; older adults allocate their attention less to negative information than to positive information (e.g., Isaacowitz et al., 2006a, 2006b; Knight et al., 2007) and remember proportionally less negative than positive information compared with younger adults (see Mather & Carstensen, 2005; Scheibe & Carstensen, 2010, for reviews). However, further investigation is needed to examine whether the age by valence interaction observed in the current study is associated with the positivity effect (biases against negative or toward positive information), or other factors secondary to reversal learning, such as older adults' poorer ability to recognise negative facial expressions (Murphy & Isaacowitz, 2010) affecting their reversal-learning abilities.

Previous studies have suggested at least two possible explanations for age-related declines in reversal learning. First, structural and functional changes of reward system among older adults may account for their impairment in reversal learning (Marschner et al., 2005). Second, older adults have greater physiological responses during anticipation of gains than during anticipation of losses (Denburg et al., 2006; Samanez-Larkin et al., 2007), which may result in overall decline in reversal learning, as this type of learning requires the ability to learn from both positive and negative outcomes. Our results revealed that older adults performed most efficiently with the absence of negative outcomes, which is more consistent with the second explanation suggesting that older adults' performance is specifically impaired for learning in situation with negative outcomes. A bias against negative information has also been observed in attention and memory among older adults, compared with younger adults (see

Mather & Carstensen, 2005, for a review). Hence, across different cognitive domains including attention, memory, and reversal learning, negative (compared to positive) valence seems to impair older adults' performance.

It is also possible that the hypotheses discussed above are not mutually exclusive, and age-related decline in reversal learning has multiple causes. In a recent fMRI study, younger adults activated the ventral striatum significantly more when stimulus–reward contingencies had been learned compared to when searching for a correct target, whereas older adults showed the opposite pattern (Mell et al., 2009). Furthermore, they found that younger adults recruited the dorsolateral prefrontal cortex during the initial stage of learning, while older adults recruited the same area after learning had occurred. Taken together with above-mentioned studies suggesting age differences in neural and physiological responses during reward-based learning, it is plausible that age-related differences and similarities can be found in various aspects of learning, such as phases of learning (e.g., anticipatory, acquisition, feedback phases) and types of cues indicating that learning has taken place (e.g., positive and negative feedback). Further investigation is needed to examine when and how age affects different aspects of reward-based learning.

The current study has some limitations. There were relatively small sample sizes and numbers of trials in the three experiments. We used simple reversal-learning tasks with few trials that would resemble everyday learning situations; however, it is possible that age differences observed in the current experiments would not apply to more complex situations requiring more rapid information update and a higher level of decision-making abilities. Another potential criticism is that the negative conditions, where participants received neutral or negative feedback upon their correct response, would not be applicable to real-life learning situations. However, although the negative conditions may not completely simulate real-life situations, in everyday life it is important to learn from negative outcomes in order to later predict which options will lead to negative outcomes.

In summary, the current study provides important new information suggesting that positive and negative context differentially affects older adults' reversal learning about non-emotional information (in this case, which neutral face is the "correct" response). Future research should examine whether older adults' responsiveness to positive versus negative information could be extended to other types of learning and how to utilise the valence effect to enhance general learning abilities among older adults.

REFERENCES

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision*, *10*(4), 443–446.

Charles, S., 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. doi:10.1037/0096-3445.132.2.310

Comblain, C., D'Argembeau, A., Van der Linden, M., & Aldenhoff, L. (2004). The effect of aging on the recollection of emotional and neutral pictures. *Memory*, *12*, 673–684. doi:10.1080/096582103 44000477

Denburg, N. L., Buchanan, T. W., Tranel, D., & Adolphs, R. (2003). Evidence for preserved emotional memory in normal older adults. *Emotion*, *3*, 239–253. doi:10.1037/1528-3542.3.3.239

Denburg, N. L., Recknor, E. C., Bechara, A., & Tranel, D. (2006). Psychophysiological anticipation of positive outcomes promotes advantageous decision-making in normal older persons. *International Journal of Psychophysiology*, *61*, 19–25. doi:10.1016/j.ijpsycho.2005.10.021

Denburg, N. L., Tranel, D., & Bechara, A. (2004). The ability to decide advantageously declines prematurely in some normal older persons. *Neuropsychologia*, *43*, 1099–1106. doi:10.1016/j.neuropsychologia.2004.09.012

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. doi:10.3758/BRM.42.1.351

Ekman, P., & Friesen, W. (1976). *Pictures of facial affect* [Photographs]. (Available from Human Interaction

Laboratory, UCSF, HIL-0984, San Francisco, CA 94143, USA)

Fung, H. H., Isaacowitz, D. M., & Lu, A. Y. (2010). Interdependent self-construal moderates age-related negativity reduction effects in memory. *Psychology and Aging*, 25, 321–329. doi:10.1037/a0019079

Fung, H. L., Isaacowitz, D. M., Lu, A. Y., Wadlinger, H. A., Goren, D., & Wilson, H. R. (2008). Age-related positivity enhancement is not universal: Older Chinese look away from positive stimuli. *Psychology and Aging*, 23, 440–446. doi:10.1037/0882-7974.23.2.440

Glisky, E. L., & Marquine, M. J. (2009). Semantic and self-referential processing of positive and negative trait adjectives in older adults. *Memory*, 17, 144–157. doi:10.1080/09658210802077405

Grühn, D., Scheibe, S., & Baltes, P. B. (2007). Reduced negativity effect in older adults' memory for emotional pictures: The heterogeneity–homogeneity list paradigm. *Psychology and Aging*, 22, 644–649. doi:10.1037/0882-7974.22.3.644

Grühn, D., Smith, J., & Baltes, P. B. (2005). No aging bias favoring memory for positive material: Evidence from a heterogeneity–homogeneity list paradigm using emotionally toned words. *Psychology and Aging*, 20, 579–588 doi:10.1037/0882-7974.20.4.579

Isaacowitz, D. M., Allard, E., Murphy, N. A., & Schlangel, M. (2009). The time course of age related preferences towards positive and negative stimuli. *Journal of Gerontology: Psychological Sciences*, 64B, 188–192. doi:10.1093/geronb/gbn036

Isaacowitz, D. M., Toner, K., Goren, D., & Wilson, H. R. (2008). Looking while unhappy: Mood congruent gaze in young adults, positive gaze in older adults. *Psychological Science*, 19, 848–853. doi:10.1111/j.1467-9280.2008.02167.x

Isaacowitz, D. M., Toner, K., & Neupert, S. D. (2009). Use of gaze for real-time mood regulation: Effects of age and attentional functioning. *Psychology and Aging*, 24, 989–994. doi: 10.1037/a0017706

Isaacowitz, D. M., Wadlinger, H. A., Goren, D., & Wilson, H. R. (2006a). Is there an age-related positivity effect in visual attention? A comparison of two methodologies. *Emotion*, 6, 511–516 doi:10.1037/1528-3542.6.3.511

Isaacowitz, D. M., Wadlinger, H. A., Goren, D., & Wilson, H. R. (2006b). Selective preference in visual fixation away from negative images in old age? An eye tracking study. *Psychology and Aging*, 21, 40–48. doi:10.1037/0882-7974.21.1.40

Kensinger, E. A., Brierley, B., Medford, N., Growdon, J. H., & Corkin, S. (2002). Effects of normal aging and Alzheimer's disease on emotional memory. *Emotion.*, 2, 118–134 doi:10.1037/1528-3542.2.2.118

Knight, M., Seymour, T. L., Gaunt, J. T., Baker, C., Nesmith, K., & Mather, M. (2007). Aging and goal-directed emotional attention: Distraction reverses emotional biases. *Emotion*, 7, 705–714. doi:10.1037/1528-3542.7.4.705

Ko, S. G., Lee, T. H., Yoon, H. Y., Kwon, J. H., & Mather, M. (2010). How does context affect assessments of facial emotion? The role of culture and age. *Psychology and Aging*. Advance online publication. doi:10.1037/a0020222

Kringelbach, M. L., & Rolls, E. T. (2003). Neural correlates of rapid reversal learning in a simple model of human social interaction. *NeuroImage*, 20, 1371–1383. 1 doi:10.1016/S1053-8119(03)00393-8

Kwon, Y., Scheibe, S., Samanez-Larkin, G. R., Tsai, J. L., & Carstensen, L. L. (2009). Replicating the positivity effect in picture memory in Koreans: Evidence for cross-cultural generalizability. *Psychology and Aging*, 24, 748–754. doi:10.1037/a0016054

Langeslag, S. J. E., & van Strien, J. W. (2009). Aging and emotional memory: The co-occurrence of neurophysiological and behavioral positivity effects. *Emotion*, 9, 369–377. doi:10.1037/a0015356

Leclerc, C. M., & Kensinger, E. A. (2008). Effects of age on detection of emotional information. *Psychology and Aging*, 23, 209–215. doi:10.1037/0882-7974.23.1.209

Marschner, A., Mell, T., Wartenburger, I., Villringer, A., Reischies, F. M., & Heekeren, H. R. (2005). Reward-based decision-making and aging. *Brain Research Bulletin*, 67, 382–390. doi:10.1016/j.brainresbull.2005.06.010

Mather, M., & Carstensen, L. L. (2003). Aging and attentional biases for emotional faces. *Psychological Science*, 14, 409–415. doi:10.1111/1467-9280.01455

Mather, M., & Carstensen, L. L. (2005). Aging and motivated cognition: The positivity effect in attention and memory. *Trends in Cognitive Sciences*, 9, 496–502. doi:10.1016/j.tics.2005.08.005

Mather, M., & Knight, M. (2005). Goal-directed memory: The role of cognitive control in older adults' emotional memory. *Psychology and Aging*, 20, 554–570. doi:10.1037/0882-7974.20.4.554

Mather, M., & Knight, M. R. (2006). Angry faces get noticed quickly: Threat detection is not impaired

among older adults. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, 61, 54–57.

Mather, M., Knight, M., & McCaffrey, M. (2005). The allure of the alignable: Younger and older adults' false memories of choice features. *Journal of Experimental Psychology: General*, 134, 38–51. doi:10.1037/0096-3445.134.1.38

Mell, T., Heekeren, H. R., Marschner, A., Wartenburger, I., Villringer, A., & Reischies, F. M. (2005). Effect of aging on stimulus–reward association learning. *Neuropsychologia*, 43, 554–563. doi:10.1016/j.neuropsychologia.2004.07.010

Mell, T., Wartenburger, I., Marschner, A., Villringer, A., Reischies, F. M., & Heekeren, H. R. (2009). Altered function of ventral striatum during reward-based decision making in old age. *Frontiers in Human Neuroscience*, 3, 34. doi:10.3389/neuro.09.034.2009

Murphy, N. A., & Isaacowitz, D. M. (2008). Preferences for emotional information in older and younger adults: A meta-analysis of memory and attention tasks. *Psychology and Aging*, 23, 263–286. doi:10.1037/0882-7974.23.2.263

Murphy, N. A., & Isaacowitz, D. M. (2010). Age effects and gaze patterns in recognising emotional expressions: An in-depth look at gaze measures and covariates. *Cognition and Emotion*, 24, 436–452. doi:10.1080/02699930802664623

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision*, 10, 437–442.

Petrican, R., Moscovitch, M., & Schimmack, U. (2008). Cognitive resources, valence, and memory retrieval of emotional events in older adults. *Psychology and Aging*, 23, 585–594. doi:10.1037/a0013176

Rosler, A., Ulrich, C., Billino, J., Sterzer, P., Weidauer, S., Bernhardt, T., et al. (2005). Effects of arousing emotional scenes of the distribution of visuospatial attention: Changes with aging and early subcortical vascular dementia. *Journal of the Neurological Sciences*, 229–230, 109–116.

Samanez-Larkin, G. R., Gibbs, S. E. B., Khanna, K., Nielsen, L., Carstensen, L. L., & Knutson, B. (2007). Anticipation of monetary gain but not loss in healthy older adults. *Nature Neuroscience*, 10, 787–791. doi:10.1038/nn1894

Scheibe, S., & Carstensen, L. L. (2010). Emotional aging: Recent findings and future trends. *Journals of Gerontology Series B-Psychological Sciences and Social Sciences*, 65, 135–144. doi:10.1093/geronb/gbp132

Tomaszczyk, J. C., Fernandes, M. A., & MacLeod, C. M. (2008). Personal relevance modulates the positivity bias in recall of emotional pictures in older adults. *Psychonomic Bulletin & Review*, 15, 191–196. doi:10.3758/PBR.15.1.191

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., et al. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research*, 168, 242–249. doi:10.1016/j.psychres.2008.05.006

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*, 54, 1063–1070. doi:10.1037/0022-3514.54.6.1063

Weiler, J. A., Bellebaum, C., & Daum, I. (2008). Aging affects acquisition and reversal of reward-based associative learning. *Learning & Memory*, 15, 190–197. doi:10.1101/lm.890408

Willis, M. L., Palermo, R., Burke, D., Atkinson, C. M., & McArthur, G. (2010). Switching associations between facial identity and emotional expression: A behavioural and ERP study. *NeuroImage*, 50, 329–339.