

Attenuating Age-Related Learning Deficits: Emotional Valenced Feedback Interacts With Task Complexity

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Previous research reveals that older adults sometimes show enhanced processing of emotionally positive stimuli relative to negative stimuli, but that this positivity bias reverses to become a negativity bias when cognitive control resources are less available. In this study, we test the hypothesis that emotionally positive feedback will attenuate well-established age-related deficits in rule learning whereas emotionally negative feedback will amplify age deficits—but that this pattern will reverse when the task involves a high cognitive load. Experiment 1 used emotional face feedback and revealed an interaction among age, valence of the feedback, and task load. When the task placed minimal load on cognitive control resources, happy-face feedback attenuated age-related deficits in initial rule learning and angry-face feedback led to age-related deficits in initial rule learning and set shifting. However, when the task placed a high load on cognitive control resources, we found that angry-face feedback attenuated age-related deficits in initial rule learning and set shifting whereas happy-face feedback led to age-related deficits in initial rule learning and set shifting. Experiment 2 used less emotional point feedback and revealed age-related deficits in initial rule learning and set shifting under low and high cognitive load for point-gain and point-loss conditions. The research presented here demonstrates that emotional feedback can attenuate age-related learning deficits—but only positive feedback for tasks with a low cognitive load and negative feedback for tasks with high cognitive load.

Keywords: normal aging, learning, set shifting, emotional processing

One in eight people in the United States are currently above the age of 65, and this number is expected to increase to one in five by the year 2030 (Vincent, Velkoff, & U.S. Census Bureau, 2010). Technological advancements, as well as the need to defer retirement in the current economic climate, underscore the importance of continued learning throughout life. Age-related deficits in learning are well documented. Older adults often have particular trouble learning tasks that rely on executive function and cognitive control mechanisms (Braver & Barch, 2002; Park et al., 2002; Salthouse, 2004; Verhaeghen & Cerella, 2002; Verhaeghen, Steitz, Sliwinski,

& Cerella, 2003; however see Verhaeghen, 2011). For example, older adults generally struggle in a broad range of rule-learning and set-shifting tasks, such as the classic Wisconsin Card Sorting Task (WCST; Head, Kennedy, Rodrigue, & Raz, 2009; Gunning-Dixon & Raz, 2003; MacPherson, Phillips, & Sala, 2002).

Despite well-documented learning deficits associated with normal aging, older adults' affective processing is generally well preserved (Leclerc & Kensinger, 2008; Mather, 2012). Older adults continue to have strong emotional experiences and report enhanced emotional well-being when compared with younger adults (Carstensen, Pasupathi, Mayr, & Nesselrode, 2000; Kobau, Safran, Zack, Moriarty, & Chapman, 2004). It is interesting to note that whether older adults process positive or negative emotional information more effectively can differ as a function of available cognitive control resources. Specifically, when cognitive control resources are available, older adults show enhanced processing of positive emotional information (Knight et al., 2007; Mather & Knight, 2005; Petrican, Moscovitch, & Schimrack, 2008); however, this tendency can reverse to favor negative information when cognitive control resources are less available (Knight et al., 2007; Mather & Knight, 2005).

The goal of the study presented here is to explore the possibility that age-related enhancements in the processing of emotional information might be leveraged to attenuate or even reverse some well-established age-related deficits in learning. The social and

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cognitive neuroscience literatures suggest considerable overlap between set shifting and emotional processing, making this a possibility worth exploring (Davidson & Irwin, 1999; Monchi, Petrides, Petre, Worsley, & Dagher, 2001; Ochsner & Gross, 2005). For example, the WCST, a well-studied set-shifting task, is known to place large demands on lateral frontal regions such as the dorsolateral and ventrolateral prefrontal cortex (Monchi et al., 2001). These same regions have been shown to be involved in the processing of emotional information (Anderson, Christoff, Panitz, De Rosa, & Gabrieli, 2003; Ochsner et al., 2004; Öhman, Flykt, & Esteves, 2001). Thus, emotion processing centers in the lateral prefrontal cortex may compete for resources during set shifting.

We focus on a learning task that relies on executive function and is similar to the popular WCST. The task requires participants to learn rules (initial rule learning) and, once the rule is learned, to switch from a learned to a novel rule (set shifting). Our approach is to compare learning under conditions in which trial-by-trial feedback is highly emotional, presented in the form of happy or angry faces, to conditions in which trial-by-trial feedback is less emotional, presented in the form of point gain or point loss. (In the Appendix, we present the results from a small-scale pilot study that verifies that face feedback is perceived as more emotional than point feedback.) To foreshadow, our results suggest that age-related deficits in rule learning and set shifting are more malleable than previously thought. Under the appropriate feedback conditions, age-related deficits can be attenuated. The age-related effects on learning depend on a systematic interaction between the cognitive-control demands of the task and the emotional valence of the feedback.

Age-Related Learning Deficits

Age-related performance deficits are seen across a multitude of cognitive domains, including inductive reasoning, spatial orientation, perceptual speed, numeric ability, verbal ability, and memory (Schaie, 1996). Normal aging is also associated with declines in learning, especially for tasks that rely on executive functions such as working memory and attention (Braver & Barch, 2002; Park et al., 2002; Salthouse, 2004; Verhaeghen & Cerella, 2002; Verhaeghen et al., 2003). These include many forms of rule-based category learning (Maddox, Pacheco, Reeves, Zhu, & Schnyer, 2010; Racine, Barch, Braver, & Noelle, 2006) as well as tasks that require set shifting (Gunning-Dixon & Raz, 2003; Head et al., 2009; MacPherson et al., 2002). Because of the prevalence of rule-based learning and set shifting in everyday life, it would be highly advantageous to develop task-specific feedback training protocols that enhance these forms of learning in older adults. This is the overriding aim of the study presented here.

Cognitive Control and Emotional Processing in Older Adults

Older adults process positive emotional content more deeply than negative emotional content compared with younger adults, an age difference known as the “positivity effect” (Mather & Carstensen, 2005). Although the positivity effect is not always observed (e.g., see Grühn, Scheibe, & Baltes, 2007; Murphy & Isaacowitz, 2008), it is frequently seen in the domains of choice (Mather, Knight, & McCaffrey, 2005), attention (Isaacowitz, 2006;

Mather & Carstensen, 2003), and memory (Grady, Hongwanishkul, Keightley, Lee, & Hasher, 2007; Kennedy, Mather, & Carstensen, 2004). For instance, when shown positive, negative, and neutral pictures, older adults recall more positive pictures and fewer negative pictures than younger adults (Charles, Mather, & Carstensen, 2003).

Mather and colleagues argue that older adults’ positivity bias is the result of goal-directed processes and thus depends on cognitive control resources and executive function processes (Kryla-Lighthall & Mather, 2009; Mather & Knight, 2005; Nashiro, Sakaki, & Mather, 2012). Reduced cognitive control resources should attenuate the positivity effect in attention and memory. Mather and Knight (2005) tested this hypothesis by having older adults view pictures under full-attention conditions or with a secondary task that divided attention and required working memory resources. In the full-attention condition, older adults recalled more positive than negative pictures whereas younger adults recalled more negative than positive pictures. This is consistent with a positivity effect. However, in the divided-attention condition, both groups recalled more negative pictures than positive pictures. Other results suggesting that cognitive control processes contribute to the positivity effect have been observed by Knight et al. (2007); Isaacowitz, Toner, and Neupert (2009); Petrican et al., (2008); and Orgeta (2011).

The Research Presented Here

The goal of the research presented here is to determine whether enhanced emotional processing in older adults can be used to attenuate well-established age-related learning deficits. We use highly emotional information in the form of happy or angry faces as feedback during learning. In the “happy-face feedback” condition, a correct response is followed by the presentation of a very happy face whereas an incorrect response is followed by the presentation of a mildly happy face. In the “angry-face feedback” condition, a correct response is followed by the presentation of a mildly angry face whereas an incorrect response is followed by the presentation of a very angry face.

The research presented here used a very general learning task that was modeled after the classic WCST (Heaton, 1980). The task allowed us to separately examine age and emotional feedback effects on initial rule learning and after a rule switch (i.e., set shifting). We directly manipulated the cognitive-control demands associated with the learning task by manipulating the number of stimulus dimensions and the number of categories, thus creating a low and a high cognitive control load version of the task (see *Method* for details). We predicted an interaction between the valence of the face feedback (happy vs. angry) and the cognitive-control demands of the learning task (low vs. high) on age-based differences in performance. In the low-load version of the task, we predicted that older adults would have enough cognitive-control resources available to enhance positive emotional feedback processing in the happy-face feedback condition, thus attenuating age-related learning deficits, whereas large age-related deficits would be observed in the angry-face-feedback condition. On the other hand, in the high load version of the task, we predicted that older adults would not have enough cognitive control resources available to enhance positive emotional feedback processing. Instead, they would show enhanced negative emotional feedback

processing, thus attenuating age-related learning deficits in the angry-face feedback condition, whereas large age-related deficits would be observed in the happy-face feedback condition.

A relevant study by Nashiro and colleagues (Nashiro, Mather, Gorlick, & Nga, 2011) used a simple learning task in which older and younger participants were presented with two neutral faces on each trial. Participants were asked to choose the face that would change into a happy face or avoid the face that would change into an angry face. After five to eight consecutive correct trials, the correct face switched unbeknownst to the participant. Older adults made significantly more errors than younger adults in the angry-face feedback condition but were statistically equal to younger adults in the happy-face feedback condition. This task involves only two relevant stimuli, placing low demand on cognitive control. As predicted, when cognitive control resources were available, happy-face feedback attenuated age-related learning deficits.

This is an important study that yielded promising results. Even so, it leaves several gaps in our understanding. Nashiro et al. used faces as the categorized stimuli and feedback, therefore it is unclear whether these results would generalize to stimuli that were not intrinsically associated with the feedback. Second, Nashiro et al. focuses only on a simple, low-load condition. In our day-to-day lives learning often comprises more complex tasks that depend on competing neural networks. Research suggests that cognitive load is critical for emotional biases; however, to date no research has directly compared the effect of cognitive load on age-related learning differences given emotional feedback. Finally, Nashiro et al. focused on one overall measure of performance (number of errors); however, we can learn more about what phase of learning is driving these effects by breaking performance down into initial rule learning and set shifting.

Experiment 1

Experiment 1 examined age-related changes in rule learning and set shifting as a function of the valence of emotional face feedback (happy vs. angry) as well as that of the cognitive load (low vs. high) associated with solving the task. To determine whether the emotional aspect of the face feedback was critical, Experiment 2 serves as a replication of Experiment 1, but with the emotional face feedback replaced with less emotional point feedback.

Method

Participants. Thirty older adults (age: $M_{OldLow} = 66.87$; $Range_{OldLow} = 60-79$) and 37 younger adults (age: $M_{YoungLow} = 21.74$; $Range_{YoungLow} = 18-35$) participated in the low-cognitive-load condition, and 36 older adults (age: $M_{OldHigh} = 66.67$; $Range_{OldHigh} = 60-82$) and 40 younger adults (age: $M_{YoungHigh} = 20.08$; $Range_{YoungHigh} = 18-26$) participated in the high-cognitive-load condition for monetary compensation. Older adults were given a large battery of neuropsychological tests during a prescreening session, including the Wechsler Adult Intelligence Scale-Fourth (Wechsler, 1997), the Stroop test (Stroop, 1935), the WCST (Heaton, 1980), the trail-making test (Corrigan & Hinkeldey, 1987), and the Wechsler Memory Scale. All results were normalized for age using standardized procedures and converted to Z scores. Participants that scored more than 2 standard deviations below the mean for memory, executive function, and attention

were excluded from the study. No age differences emerged on the Wechsler Adult Intelligence Scale (WAIS) vocabulary subtest (Wechsler, 1997). Subjective ratings of stress and health were also taken before completing the task, and no age differences emerged. Age, years of education, and scaled WAIS vocabulary scores are displayed in Table 1.

Materials and procedure. Participants in the low-cognitive-load condition completed a simple rule-learning task with four stimuli constructed from a factorial combination of two binary-valued dimensions. On each of the 64 trials, participants were presented with one of the four stimuli and asked to categorize it into one of two categories. Unbeknownst to the participant, only one of the two stimulus dimensions was relevant to the categorization rule; along that dimension, each binary value was associated with one of the two categories. Participants were asked to pretend that they were ecologists and told that their task was to protect the environment by sorting cattails, frogs, ducks, or dragonflies into native and foreign species using trial-by-trial feedback (see upper panel of Figure 1). Different surface features were used for the happy-face feedback and angry-face feedback conditions and were selected randomly from the four possible stimuli sets (cattails, frogs, ducks, or dragonflies). Once participants correctly categorized 10 consecutive stimuli, the rule changed without their knowledge and the irrelevant dimension became relevant. After the 64th trial, an exit screen provided information about whether the participant had reached their goal or not (defined below).

Participants in the high-cognitive-load condition completed a complex rule-learning task with 64 stimuli constructed from the factorial combination of three stimulus dimensions, with four possible values for each dimension. On each of 128 trials, participants were presented with 1 of the 64 stimuli and asked to categorize it into one of four categories. Unbeknownst to the participant, only one of the three stimulus dimensions was relevant; along that dimension, each of the four possible values was associated with one of the four categories. Participants were either told that they had to sort dogs by breed or outfits by designer (see lower panel of Figure 1). Each participant was randomly assigned to a cover story (breed or designer) and a feedback condition (happy or angry). Once participants correctly categorized 10 consecutive stimuli the rule changed (without their knowledge) and one of the two irrelevant dimensions was now relevant. After the 128th trial, an exit screen provided information about whether the participant reached their goal or not (defined below).

Table 1
Participant Demographic Information

| Feedback | Cognitive load | Age group | Mean age (years) | Vocabulary Z ^a | Education ^b |
|----------|----------------|-----------|------------------|---------------------------|------------------------|
| Face | Low | Younger | 21.74 | 0.50 | 13.74 |
| | | Older | 66.87 | 1.41 | 17.70 |
| | High | Younger | 20.08 | 0.69 | 13.74 |
| Point | Low | Older | 66.67 | 1.17 | 17.33 |
| | | Younger | 21.88 | 0.43 | 13.84 |
| | High | Older | 67.35 | 1.34 | 17.97 |
| | | Younger | 20.55 | 0.99 | 13.83 |
| | Older | Younger | 20.55 | 0.99 | 13.83 |
| | | Older | 66.74 | 1.33 | 18.48 |

^a Vocabulary Z is the average Z score on the WAIS vocabulary measure of intelligence. ^b Education is years of education where a bachelors degree = 16 years.

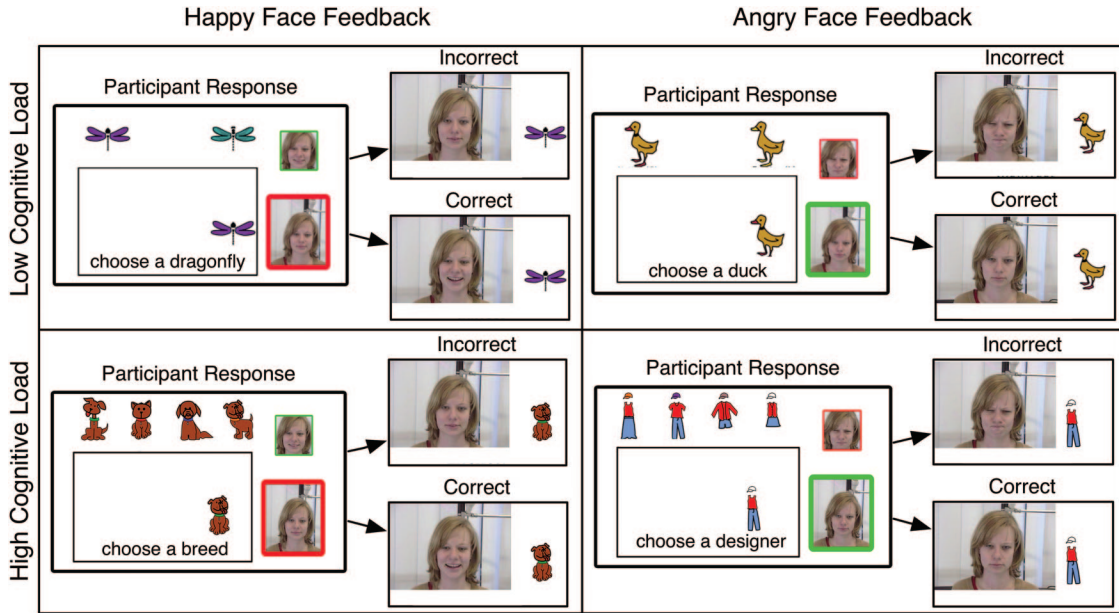


Figure 1. Screen shots from the happy- and angry-face feedback conditions from the low- and high-cognitive-load conditions. Face images have been collected from the FEED database courtesy of Frank Wallhoff: Facial Expressions and Emotion Database <http://www.mmk.ei.tum.de/~waf/fgnet/feedtum.html>, Technische Universität München 2006. Permission is given to use these images for research purposes.

Emotional face feedback was used in all conditions of Experiment 1. Participants in the low- and high-load conditions completed the task under happy-face feedback conditions and under angry-face feedback conditions. Task order (happy-face vs. angry-face feedback condition) was counterbalanced. On each trial in the happy-face feedback condition, a correct response was followed by the presentation of a face with a large smile and an incorrect response was followed by a face with a small smile (see Figure 1 for examples). In the angry-face feedback condition, a correct response was followed by the presentation of a face with a small frown and an incorrect response was followed by a face with a large frown (see Figure 1 for examples). In addition to trial-by-trial feedback, each condition had a global goal. This goal consisted of a face displayed on the right side of the screen that morphed from a neutral face to an emotional face. In the happy-face feedback condition, the goal was to make the girl very happy. In the angry-face feedback condition, the goal was to avoid making the girl very angry. The goal was attained if 80% of the responses were correct. The experiment was performed on PC computers using Flash software.

Results

In this section we examine three learning measures: overall accuracy, the number of trials needed to obtain 10 consecutive correct responses when learning the first rule (trials to first rule), and the number of trials needed to obtain 10 consecutive correct responses when learning the second rule (trials to second rule). Each measure taps into a different aspect of learning. Accuracy provides a global measure of learning, the number of trials to learn the first rule provides a measure of initial rule learning, and the number of trials to learn the second rule provides a measure of set

shifting. Table 2 includes the means and standard errors for all T2 conditions.

Accuracy. Overall accuracy was calculated for each participant, and a 2 (age) × 2 (valence) × 2 (cognitive load) mixed

Table 2
Summary Statistics for All Conditions

| | Task load | Feedback | Younger | Older |
|-----------------------|------------|--------------|--------------|--------------|
| Accuracy rate | High | Happy face | 0.83 (0.015) | 0.74 (0.016) |
| | | Angry face | 0.78 (0.017) | 0.8 (0.017) |
| | | Point gain | 0.84 (0.015) | 0.77 (0.015) |
| | Low | Happy face | 0.86 (0.016) | 0.82 (0.017) |
| | | Angry face | 0.85 (0.017) | 0.8 (0.019) |
| | | Point gain | 0.86 (0.014) | 0.83 (0.015) |
| Initial rule learning | High | Happy face | 14.53 (1.78) | 24.83 (1.88) |
| | | Angry face | 22.3 (2.44) | 20.89 (2.57) |
| | | Point gain | 13.87 (1.74) | 21.07 (1.71) |
| | Low | Happy face | 15.3 (1.85) | 22.03 (1.85) |
| | | Angry face | 14.1 (1.89) | 15.67 (2.06) |
| | | Point gain | 14.22 (2.53) | 17.07 (2.81) |
| Set shifting | High | Happy face | 13.44 (1.63) | 16.58 (1.71) |
| | | Angry face | 15.32 (1.77) | 16.87 (1.85) |
| | | Point gain | 15.32 (1.77) | 16.87 (1.85) |
| | Low | Happy face | 19.53 (2.42) | 26.58 (2.55) |
| | | Angry face | 18.7 (2.05) | 16.03 (2.17) |
| | | Point gain | 14.3 (1.62) | 17.48 (1.60) |
| Low | Happy face | 14.77 (2.07) | 19.07 (2.03) | |
| | Angry face | 15.43 (2.52) | 23.4 (2.8) | |
| | Point gain | 18.6 (2.14) | 24.27 (2.37) | |
| | | Point loss | 17.03 (1.53) | 22.23 (1.6) |
| | | Point loss | 16.53 (1.94) | 22.1 (2.03) |

Note. Values in parentheses indicate standard errors.

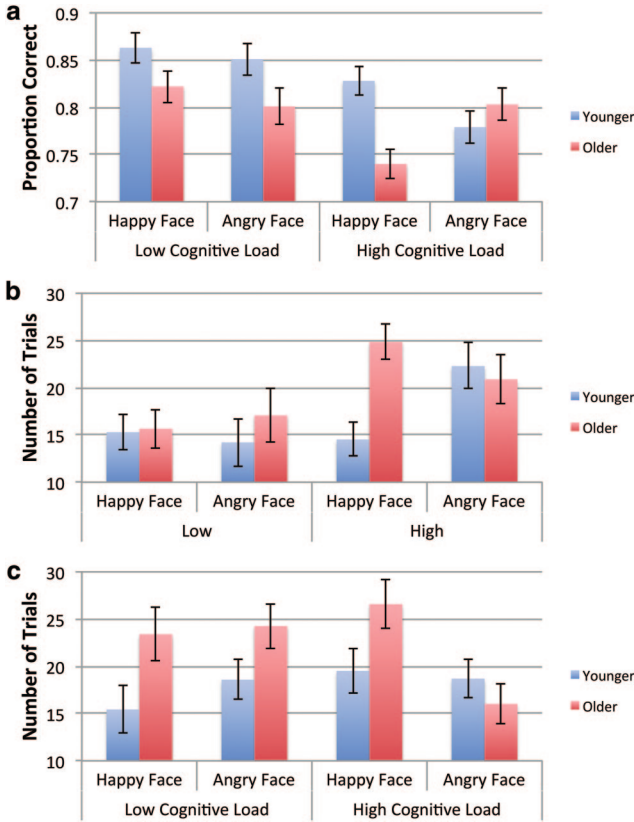


Figure 2. Experiment 1: (a) Proportion correct for older and younger adults for the happy- and angry-face feedback conditions under low and high cognitive load. (b) Number of trials to learn the first rule for older and younger adults for the happy- and angry-face feedback conditions under low and high cognitive load. (c) Number of trials to learn the second rule for older and younger adults for the happy- and angry-face feedback conditions under low and high cognitive load. Standard error bars are included.

analysis of variance (ANOVA) was conducted (see Figure 2a). There was a main effect of age, $F(1, 139) = 8.61, p = .004, \eta^2 = 0.06$, with younger adults performing more accurately than older adults ($M_{Older} = .79; M_{Younger} = .83$), and a main effect of task load, $F(1, 139) = 12.37, p = .001, \eta^2 = 0.08$, with superior performance in the low-cognitive-load task relative to the high-cognitive-load task ($M_{Low} = .83; M_{High} = .79$). These effects were qualified by a significant three-way age \times valence \times cognitive load interaction, $F(1, 139) = 8.23, p = .004, \eta^2 = 0.06$, and no other significant effects.

To decompose the three-way interaction, we conducted age \times valence ANOVAs separately for the low- and high-cognitive-load conditions. In the low-cognitive-load condition, the only significant effect was a main effect of age, $F(1, 65) = 7.91, p = .007, \eta^2 = 0.11$, with younger adults performing more accurately than older adults ($M_{Older} = .81; M_{Younger} = .86$). Although the interaction was not significant, we did predict a priori that the age-related learning deficit should be attenuated in the happy-face feedback condition relative to the angry-face feedback condition. The effect of age was significant for happy-, $t(65) = 2.34, p = .02$, and angry-face feedback, $t(65) = 2.23, p = .03$.

In the high-cognitive-load condition, there were no main effects of age or valence, but there was an age \times valence interaction, $F(1, 74) = 11.93, p = .001, \eta^2 = 0.14$. Older adults performed as well as younger adults in the angry-face feedback condition, $t(74) = 0.89, p = .38, ns, (M_{Older} = 0.80; M_{Younger} = 0.78)$, but older adults performed significantly worse than younger adults in the happy-face feedback condition, $t(74) = 3.44, p = .001, (M_{Older} = 0.74; M_{Younger} = .83)$. In addition, older adults were significantly more accurate with angry-face feedback than with happy-face feedback, $t(35) = 2.77, p = .009$, whereas younger adults were significantly less accurate with angry-face feedback compared with happy-face feedback, $t(39) = 2.14, p = .04$.

Trials to first rule. The number of trials needed to learn the first rule was calculated for each participant and a 2 (age) \times 2 (valence) \times 2 (cognitive load) mixed ANOVA was conducted (see Figure 2b). There was a significant main effect of cognitive load, $F(1, 139) = 8.57, p = .004, \eta^2 = 0.06$, with participants taking longer to learn the first rule in the high-cognitive-load condition ($M_{Low} = 15.6; M_{High} = 20.6$). There were no main effects of age or valence and no two-way interactions; however, there was a significant age \times valence \times cognitive load interaction, $F(1, 139) = 5.84, p = .02, \eta^2 = 0.04$.

To decompose the three-way interaction, we separately conducted age \times valence ANOVAs for the low- and high-cognitive-load conditions. In the low-cognitive-load condition, there were no main effects and no interaction. We again separately examined age effects in the happy- and angry-face feedback conditions because of our a priori predictions. Older adults performed as well as younger adults in the happy-face feedback condition, $t(65) = 0.18, p = .86, ns, (M_{Older} = 15.67; M_{Younger} = 15.30)$, but they took marginally more trials than younger adults in the angry-face feedback condition, $t(65) = 1.79, p = .08, ns, (M_{Older} = 17.07; M_{Younger} = 14.22)$.

In the high-cognitive-load condition, there was no main effect of age or valence. However, there was a significant age \times valence interaction, $F(1, 74) = 5.25, p = .03, \eta^2 = 0.07$. Older adults performed as well as younger adults in the angry-face feedback condition, $t(74) = 0.30, p = .76, ns, (M_{Older} = 20.9; M_{Younger} = 22.3)$, but older adults took significantly longer to learn the first rule than younger adults in the happy-face feedback condition, $t(74) = 3.39, p = .001, (M_{Older} = 24.8; M_{Younger} = 14.5)$. In addition, older adults showed no significant difference between the number of trials needed to learn the first rule given angry-face feedback compared with happy-face feedback whereas younger adults took significantly more trials to learn the first rule given angry-face feedback compared with happy-face feedback, $t(39) = -2.11, p = .04$.

Trials to second rule. The number of trials needed to learn the second rule was calculated for each participant, and a 2 (age) \times 2 (valence) \times 2 (cognitive load) mixed ANOVA was conducted (see Figure 2c). There was a significant main effect of age, $F(1, 139) = 6.54, p = .01, \eta^2 = 0.05$, with older adults taking more trials to learn the second rule than younger adults ($M_{Older} = 22.57; M_{Younger} = 18.06$). A valence \times cognitive load interaction, $F(1, 139) = 5.71, p = .02, \eta^2 = 0.04$, also emerged, suggesting that fewer trials are needed for second rule learning with happy-face feedback in the low-cognitive-load condition, but fewer trials are needed for second rule learning with angry-face feedback in the high-cognitive-load condition.

Although the three-way interaction was not significant, we decided to explore the pattern of age effects to provide some insights into the nature of set-shifting performance. Although potentially informative, these results should be interpreted with caution. In the low-cognitive-load condition, a significant age deficit emerged in the happy-face feedback condition, $t(65) = 3.55$, $p = .001$, ($M_{Older} = 23.40$; $M_{Younger} = 15.43$), and in the angry-face-feedback condition, $t(65) = 2.09$, $p = .04$, ($M_{Older} = 24.27$; $M_{Younger} = 18.60$).

On the other hand, a different pattern emerged in the high-cognitive-load condition. Older adults took marginally more trials than younger adults to learn the second rule in the happy-face feedback condition, $t(74) = 1.60$, $p = .11$, *ns*, ($M_{Older} = 26.58$; $M_{Younger} = 19.53$), and were as fast as younger adults to learn the second rule in the angry-face feedback condition, $t(74) = .80$, $p = .42$, *ns*, ($M_{Older} = 16.03$; $M_{Younger} = 18.70$).

Discussion

This study examined age-related changes in rule learning and set shifting as a function of the valence of highly emotional face feedback (happy vs. angry) in low and high cognitive load learning tasks. Previous research suggests that older adults use cognitive control resources to process positive emotional information more deeply than negative emotional information (Knight et al., 2007; Mather & Knight, 2005; Petrican et al., 2008). However, when cognitive control resources are limited, these effects can disappear or, at times, reverse. These biases likely influence the salience of feedback during learning. Thus, we predicted a systematic interaction among age, valence of the feedback, and task cognitive load in which happy-face feedback attenuates age-related learning deficits under low-cognitive-load conditions and angry-face feedback attenuates age-related learning deficits under high-cognitive-load conditions.

For the measures of initial and overall rule learning, we found support for the predicted three-way interaction. Under low-load conditions we predicted that happy-face feedback would attenuate age-related deficits relative to angry-face feedback. We found some support for this prediction in initial learning with no significant difference between younger adults and older adults in the number of trials needed to learn the first rule in the happy-face feedback condition and an age deficit in which older adults took 2.85 more trials than younger adults in the angry-face feedback condition. For overall learning, the age-related deficit was 4% in the happy-face feedback condition and 5% in the angry-face feedback condition, yielding only a 1% difference across feedback conditions. Under high-load conditions, we predicted that angry-face feedback would attenuate age-related deficits relative to happy-face feedback. This prediction was supported. For initial learning, we found no significant difference between younger adults and older adults in the number of trials needed to learn the first rule in the angry-face feedback condition; however, we found an age-related deficit in which older adults took 10.30 more trials than younger adults in the happy-face feedback condition. Analogously, for overall learning, older adults were as accurate as younger adults in the angry-face feedback condition, and the age-related deficit was 9% in the happy-face feedback condition. Thus, age-related deficits in initial and overall rule learning were

attenuated when the cognitive load was high and angry-face feedback was used.

It is interesting to note that the initial learning benefit observed for older adults in the low-cognitive-load condition with happy-face feedback was attenuated significantly once the second rule was introduced and set shifting was required. In fact, the age-related set-shifting deficit was larger in the happy-face feedback condition (7.97 trials) than in the angry-face feedback condition (5.67 trials). Thus, it appears that the modest initial learning for older adults with happy-face feedback came at the cost of reduced flexibility in processing, making it more difficult to shift set.

However, in the high-cognitive-load condition, older adults were as fast to shift set as younger adults in the angry-face feedback condition (yielding a 2.67 trial set-shifting advantage) whereas older adults were marginally slower to shift set than younger adults in the happy-face feedback condition (yielding a 7.05 trial set-shifting deficit). Thus, the age-related performance advantage under high-cognitive-load conditions with angry-face feedback was large and robust across all three measures of learning.

Although we predicted that the highly emotional nature of the face feedback is what led to the complex pattern of age-related deficits and performance advantages, it is possible that these effects also hold with less emotional feedback in the form of points gained and points lost. Experiment 2 directly addresses this possibility.

Experiment 2

Experiment 1 revealed a systematic interaction among age, valence of the highly emotional face feedback, and cognitive load associated with solving the task. When task demands on cognitive control are low, happy-face feedback attenuates deficits in overall learning, initial rule learning, and, to a lesser extent, set shifting. However, during a complex task that places high demands on cognitive control, angry-face feedback attenuates these age-related learning deficits. It is still unclear whether this complex three-way interaction generalizes to all valenced feedback or only applies to emotional face feedback.

One study comparing brain activation in younger adults receiving social face feedback versus monetary feedback found that monetary feedback recruits a wide range of brain regions, including the medial orbitofrontal cortex (OFC), striatum, superior frontal gyrus, medial temporal lobe, and insula (Lin, Adolphs, & Rangel, 2012). However, social feedback activated a smaller neural network mostly consisting of the medial OFC. The OFC has been implicated in neural functions that are important for set shifting such as reversal learning (e.g., Fellows & Farah, 2003). Furthermore, recent research indicates that the OFC is more involved in updating emotional associations than nonemotional associations (Nashiro, Sakaki, Nga, & Mather, 2012; Sakaki, Niki, & Mather, 2011). This suggests that social and monetary feedback act through overlapping but separate neural networks; however, it is unclear whether these differences affect set-shifting learning outcomes.

Another study suggests that monetary feedback in aging shows similar processing biases as those seen with face feedback. Samanez-Larkin and colleagues (2007) found that older and younger adults show similar patterns of brain activation while

anticipating monetary gain; however, older adults show less brain activation while anticipating monetary loss. Although this study suggests that older adults are processing positive monetary feedback different than negative monetary feedback, it is unclear if the anticipatory biases affect learning outcomes in older adults. Experiment 2 examines whether the performance interaction observed in Experiment 1 holds when highly emotional face feedback is replaced with less emotional point feedback.

Methods

Participants. Thirty-one older adults (age: $M_{OldLow} = 67.35$; $Range_{OldLow} = 61-78$) and 34 younger adults (age: $M_{YoungLow} = 21.88$; $Range_{YoungLow} = 18-35$) participated in the low cognitive load task, and 31 older adults (age: $M_{OldHigh} = 66.74$; $Range_{OldHigh} = 60-79$) and 30 younger adults (age: $M_{YoungHigh} = 20.55$; $Range_{YoungHigh} = 18-26$) participated in the high cognitive load task for monetary compensation. Older adults were given the same battery of neuropsychological tests as described in Experiment 1 and the same exclusion criteria were applied. In addition, younger and older adults were administered the WAIS vocabulary subtest (Wechsler, 1997) and no age group differences emerged. Subjective ratings of stress and health were also taken before completing the task, and no age differences emerged.

Materials and procedure. The materials and procedures were identical to Experiment 1 except that highly emotional face feedback was replaced with less emotional point feedback (see Figure 3). In the “point-gain” feedback condition, a correct response was followed by a display of +3 points and an incorrect response was followed by a display of +1 point. In the “point-loss” feedback condition, a correct response was followed by a display of -1 point and an incorrect response was followed by a display of -3 points. In the point-gain feedback condition, the goal was to fill the

point meter to the top whereas in the point-loss feedback condition, the goal was to avoid letting the point meter drop to the bottom. Their goal was attained if participants achieved 80% accuracy. As in Experiment 1, task order was counterbalanced and surface features were randomly assigned. The experiment was performed on PC computers using Flash software.

Results

Following the procedures outlined in Experiment 1, we examined overall accuracy, trials to learn the first rule, and trials to learn the second rule.

Accuracy. Overall accuracy was calculated for each participant, and a 2 (age) \times 2 (valence) \times 2 (cognitive load) mixed ANOVA was conducted (see Figure 4a). There was a significant main effect of age, $F(1, 122) = 15.71, p < .001, \eta^2 = 0.11$, with older adults performing worse than younger adults ($M_{Older} = .80$; $M_{Younger} = .85$), and a significant main effect of cognitive load, $F(1, 122) = 4.35, p = .04, \eta^2 = 0.03$, with participants being more accurate in the low-cognitive-load condition than in the high-cognitive-load condition ($M_{Low} = .84$; $M_{High} = .81$). No other effects reached significance.

Trials to first rule. The number of trials needed to learn the first rule was calculated for each participant, and a 2 (age) \times 2 (valence) \times 2 (cognitive load) mixed ANOVA was conducted (see Figure 4b). There was a significant main effect of age, $F(1, 122) = 17.74, p < .001, \eta^2 = 0.13$, with older adults taking more trials to learn the first rule than younger adults ($M_{Older} = 19.1$; $M_{Younger} = 14.2$). No other effects reached significance.

Trials to second rule. The number of trials needed to learn the second rule was calculated for each participant, and a 2 (age) \times 2 (valence) \times 2 (cognitive load) mixed ANOVA was conducted (see Figure 4c). There was a significant main effect of age, $F(1,$

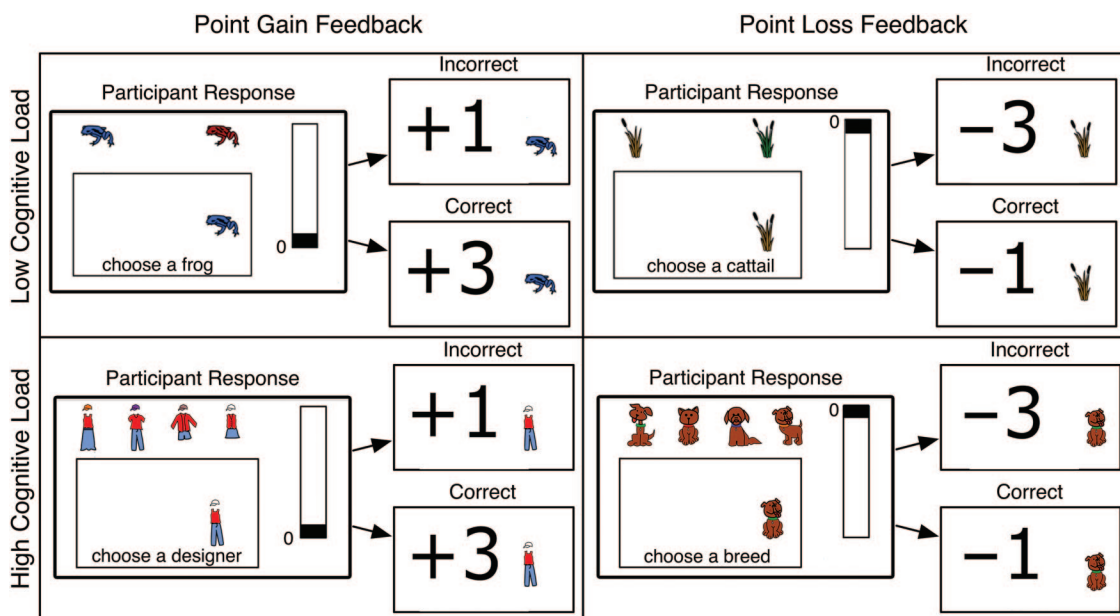


Figure 3. Screen shots from the point-gain and point-loss feedback conditions from the low- and high-cognitive-load conditions.

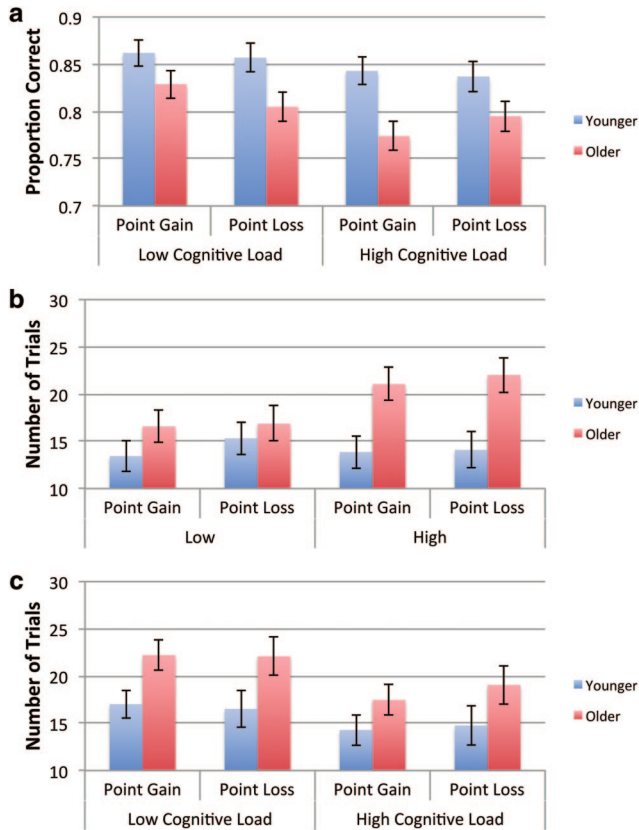


Figure 4. Experiment 2: (a) Proportion correct for older and younger adults for the point-gain and point-loss feedback conditions under low and high cognitive load. (b) Number of trials to learn the first rule for older and younger adults for the point-gain and point-loss feedback conditions under low and high cognitive load. (c) Number of trials to learn the second rule for older and younger adults for the point-gain and point-loss feedback conditions under low and high cognitive load. Standard error bars are included.

122) = 12.98, $p < .001$, $\eta^2 = 0.1$, with older adults taking more trials to learn the second rule than younger adults ($M_{Older} = 20.2$; $M_{Younger} = 15.7$), and a significant main effect of cognitive load, $F(1, 122) = 5.87$, $p = .02$, $\eta^2 = 0.05$, with participants taking more trials to learn the second rule in the high-cognitive-load condition than in the low-cognitive-load condition ($M_{low} = 19.5$; $M_{high} = 16.4$). No other effects reached significance.

Discussion

This study repeated the format of Experiment 1 but replaced emotional face feedback with less emotional point feedback. Older adults showed the learning deficits classically seen in set-shifting paradigms. Older adults were less accurate, needed more trials to learn the initial rule, and needed more trials to learn the second rule relative to younger adults. This pattern contrasts with the three-way age \times valence \times cognitive load interaction observed in Experiment 1 in which highly emotional stimuli attenuated learning deficits. The results from Experiment 2 are important because they demonstrate that the valence manipulation (positive feedback vs. negative feedback) in isolation is not sufficient to attenuate

age-related deficits. Successful learning depends on the emotional content of the feedback (happy faces vs. angry faces), and age-related deficits are still seen with less emotional feedback (point gain vs. point loss).

General Discussion

The overriding aim of this study was to see if well-established rule-learning and set-shifting deficits observed in normal aging could be attenuated by incorporating highly emotional faces as feedback. Previous research suggests that the processing of emotional information is enhanced in older adults but that the valence of enhanced information changes as a function of the cognitive control resources available for processing (Kryla-Lighthall & Mather, 2009). When cognitive control resources are readily available, positive emotional information is processed more deeply, whereas when cognitive control resources are less readily available, negative emotional information is processed more deeply (Knight et al., 2007). In addition, older adults need good cognitive control to prevent mood declines through gaze preferences for happy faces and away from angry faces (Isaacowitz et al., 2009). We hypothesized that if highly emotional information in the form of happy faces or angry faces was used as feedback, enhanced processing of emotional information might be exploited to bootstrap learning in older adults. We predicted that happy-face feedback would attenuate age-related learning deficits when the task placed minimal load on cognitive control resources whereas angry-face feedback would attenuate age-related learning deficits when the task placed a high load on cognitive-control resources.

The results from Experiment 1 supported our predictions. Under low-cognitive-load conditions older adults performed as well as younger adults in the happy-face feedback condition and showed a large initial rule-learning deficit in the angry-face feedback condition. This pattern showed a significant reversal under high-cognitive-load conditions in which older adults performed as well as younger adults in the angry-face feedback condition, but showed a large initial rule-learning deficit in the happy-face feedback condition. Unfortunately, any benefit in initial rule learning that older adults enjoyed with happy-face feedback under low-cognitive-load conditions came at a cost in reduced flexibility once the rule switched. Specifically, under low-cognitive-load conditions older adults showed a large set-shifting deficit relative to younger adults in the happy-face and angry-face feedback conditions. On the other hand, the benefit in initial rule learning that older adults enjoyed with angry-face feedback under high-cognitive-load conditions was also present once the rule switched. Specifically, under high-cognitive-load conditions older adults performed as well as younger adults in the angry-face feedback condition despite the presence of a modest set-shifting deficit in the happy-face feedback condition.

Experiment 2 repeated the procedure of Experiment 1 with the highly emotional face feedback replaced by less emotional point feedback. We predicted that point feedback would not be processed more deeply by older adults than younger adults and thus would yield age-related deficits across the board. As predicted, age-related deficits emerged for the low- and high-cognitive-load conditions when the feedback came in the form of points gained or points lost.

Taken together, these data suggest that age-related rule-learning deficits are more flexible than once thought. These deficits can be attenuated if the appropriate feedback is paired with the task demands on cognitive load to optimize the speed of initial learning and the flexibility needed to efficiently shift set. The study presented here suggests that angry-face feedback optimizes rule learning when the task is complex and places a strong demand on cognitive control resources whereas happy-face feedback optimizes rule learning when the task is simpler and places less demand on cognitive control resources.

Nashiro and colleagues (2011) examined the differential effects of happy- and angry-face feedback on older and younger adults' learning in a task with low cognitive load that required initial rule learning and rule switching. As predicted, older adults made more errors in the angry-face feedback condition than younger adults, but this deficit was attenuated with happy-face feedback. It is important to note that Nashiro and colleagues (2011) only examined an overall measure of performance—the number of errors made across the task—which obscures differential learning effects across phases of learning. The study presented here helps to fill this critical gap in our understanding of the effects of age and feedback on initial learning and set shifting. Data from the study presented here suggest that the attenuated age deficit for happy-face feedback in Nashiro et al. (2011) is most likely due to effects on initial learning and not on set shifting. Future work should more fully explore this.

Rule Learning and Set Shifting

In the study presented here we found an interesting dissociation between initial rule learning and set shifting for older and younger adults under low- and high-cognitive-load conditions. Under low-cognitive-load conditions, we found that the age-related initial rule-learning deficit tended to be attenuated with happy-face feedback, but that this came at a cost of even larger set-shifting deficits. On the other hand, under high-cognitive-load conditions, we found that the age-related initial rule-learning and set-shifting deficits were attenuated with angry-face feedback.

The nature of the feedback may be partially responsible for the dissociation between initial rule learning and set shifting. Error feedback is critical when determining if a strategy is not working and a rule shift is needed. In the happy-face condition, errors are presented as a small smile and in the angry-face condition errors are presented as a large frown. This may make angry-face errors easier to interpret because the change in emotion is larger and the emotional component of the feedback (negative) aligns with the feedback (error). This asymmetry in the emotional component with feedback would not affect initial rule learning as drastically because correct and error feedback can be used to maintain rules.

In the low-cognitive-load condition, older adults process happy-face feedback more deeply than angry-face feedback. This helps initial rule learning in which large smiles are used to guide selection of the first rule; however, small smiles indicating errors are not salient enough to elicit a rule shift. Angry-face feedback is ineffective in initial rule learning and set shifting because it is processed shallowly. In the high-cognitive-load condition, negative feedback is processed more deeply than positive feedback. Happy-face feedback is ineffective in initial rule learning and set shifting because it is processed more shallowly. Angry-face feed-

back is processed more deeply, which allows older adults to learn the initial rule and determine when to shift set through errors indicated with large frowns. This explanation is admittedly speculative, but it deserves further investigation.

Individual Differences

Given the importance of the cognitive load manipulation in the findings presented here, it is worth exploring the possibility that individual differences in executive functioning across older adults might affect the pattern of results. Previous research suggests that older adults' executive function interacts with emotional processing (Isaacowitz et al., 2009; Mather & Knight, 2005; Petrican et al., 2008). Because of our relatively small sample sizes and the fact that we did not collect measures of executive function in our younger adult sample, we deem these analyses as exploratory. Even so, some interesting patterns emerged. We used the popular Stroop interference measure as our measure of executive function (Stroop, 1935). We performed a median split on Stroop interference Z scores and classified older adults as high or low on executive functioning. Performance means for each condition are displayed in Table 3.

Experiment 1 used highly emotional face feedback to attenuate learning differences. An examination of Table 3 suggests that when executive function is good and the cognitive load is low, happy-face feedback may attenuate the age-related initial rule-learning deficit. However, under high-cognitive-load conditions, good executive function had little effect on initial rule learning. With respect to set shifting, high-functioning older adults showed

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Table 3
Summary Statistics for Older Adults Grouped by Poor or Good Executive Function Measured Using the Stroop Task

| | Task Load | Feedback | Older good EF | Older poor EF |
|-----------------------|-----------|------------|---------------|---------------|
| Accuracy rate | High | Happy face | 0.78 (0.02) | 0.69 (0.02) |
| | | Angry face | 0.82 (0.02) | 0.79 (0.03) |
| | | Point gain | 0.8 (0.02) | 0.76 (0.02) |
| | | Point loss | 0.8 (0.02) | 0.79 (0.02) |
| | Low | Happy face | 0.84 (0.02) | 0.8 (0.03) |
| | | Angry face | 0.81 (0.03) | 0.79 (0.03) |
| | | Point gain | 0.83 (0.02) | 0.83 (0.02) |
| | | Point loss | 0.82 (0.02) | 0.79 (0.02) |
| Initial rule learning | High | Happy face | 24.3 (2.53) | 25.5 (2.83) |
| | | Angry face | 21.3 (3.47) | 20.38 (3.88) |
| | | Point gain | 22.92 (2.66) | 19.72 (2.26) |
| | | Point loss | 22.23 (2.87) | 21.89 (2.44) |
| | Low | Happy face | 14.5 (2.83) | 17 (3.03) |
| | | Angry face | 16.81 (3.88) | 17.36 (4.15) |
| | | Point gain | 16.31 (2.39) | 16.87 (2.47) |
| | | Point loss | 18.81 (2.59) | 14.8 (2.67) |
| Set shifting | High | Happy face | 19.15 (3.28) | 35.88 (3.67) |
| | | Angry face | 13.95 (2.90) | 18.63 (3.25) |
| | | Point gain | 15 (2.46) | 19.28 (2.09) |
| | | Point loss | 16 (3.13) | 21.28 (2.66) |
| | Low | Happy face | 19.25 (3.67) | 28.14 (3.92) |
| | | Angry face | 22 (3.25) | 26.86 (3.47) |
| | | Point gain | 20.56 (2.22) | 24 (2.29) |
| | | Point loss | 20.5 (2.83) | 23.8 (2.92) |

Note. Values in parentheses indicate standard errors. EF = executive function.

faster set shifting than low-functioning older adults in all four conditions. Experiment 2 used less emotional point feedback and the results were more straightforward. As suggested by an examination of Table 3, in general, high-functioning older adults showed faster initial rule learning and set shifting than low-functioning older adults, but high-functioning older adults never performed at an equivalent or better level than younger adults.

Taken together, these data suggest that good executive function plays a different role in positive versus negative emotional information processing. In the low-load condition, those with good executive function show emotional biases in which happy-face feedback leads to age-related advantages in initial rule formation as well as an attenuation of the set-shifting deficit. However, older adults with poor executive function are worse than younger adults in initial rule formation and set shifting across valence. We do not see this interaction in the high-cognitive-load condition in which negative emotional information is more salient. Here, older adults show performance advantages given angry-face feedback regardless of their level of executive function. This suggests that executive processes drive emotional biases for positive but not negative emotional feedback.

Limitations

Although the results presented in this study are compelling, there are several limitations that are worth noting. First, given the importance of cognitive control demands and resources in the work presented here, a more detailed examination of individual differences in cognitive control processing and resources is in order. The preliminary analyses presented here are suggestive, but a larger sample size is needed before definitive conclusions can be drawn. In addition, although the Stroop task taps executive function, it also relies on attentional resources. It would be informative for future work to look for convergent evidence across several measures of executive function. Second, measures of affect and mood should be included in future work. We collected subjective ratings of stress and health and found no age differences. Even so, affect and mood may have differed across age groups and conditions. Although it is difficult to imagine how these might account for the systematic interaction observed in the study presented here, these measures might still be informative. In fact, it would be interesting to see how the different feedback conditions change affect and mood throughout the course of learning. These ratings could provide insights as to whether these effects are due to age differences in emotion regulation strategies or differences in the processing of emotional information (Isaacowitz & Blanchard-Fields, 2012). Finally, although the study presented here provides important insights into the way that emotionally valenced feedback affects age-related differences in rule learning, it provides no insights into other forms of learning. Contemporary cognitive theory emphasizes (at least) two systems that underlie learning: a reflective system in which processing is frontally mediated and under conscious control and a reflexive system in which processing is striatally mediated and not under conscious control (Ashby, Alfonso-Reese, Turken, & Waldron, 1998; Ashby & Maddox, 2005). The study presented here focuses on reflective (frontally mediated rule) learning. It is known that cognitive load differentially affects performance in the two learning systems (Filoteo, Lauritzen, & Maddox, 2010), but it is unclear how highly emo-

tional face feedback might affect learning in the striatal system. Future research should explore these effects.

Conclusions

This study reports the results from two experiments that examined the effects of highly emotional face feedback on initial rule learning and set shifting using tasks that involve a low or a high cognitive load. When the task placed minimal load on cognitive control resources, we found that happy-face feedback tended to attenuate the age-related initial rule-learning deficit, but that this advantage came with a cost once the rule switched. Under the same cognitive load conditions, we also found that angry-face feedback led to large age-related initial rule-learning and set-shifting deficits. However, when the task placed a heavy load on cognitive control resources, we found that angry-face feedback attenuated an age-related deficit in initial rule learning and set shifting whereas happy-face feedback led to age-related initial rule-learning and set-shifting deficits. When the highly emotional face feedback was replaced with less emotional point feedback, we found age-related performance deficits across the board.

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Appendix

Methods and Results From Small-Scale Pilot Study

Participants

Four older and four younger adults completed the pilot study. Older adults completed the same neuropsychological test battery used in Experiments 1 and 2 and met the same inclusion criteria.

Procedure

Each participant completed 12 trials in each of four feedback conditions (happy face, angry face, point gain, and point loss) from the low-cognitive-load task. After presentation of the feedback on each trial, participants were asked to rate the emotionality of the feedback on a scale from 1 to 5 in which 1 denotes low emotionality and 5 denotes high emotionality. Four condition orders were used, with one older and one younger adult completing the task in each of the following condition orders: happy-angry-gain-loss, angry-happy-loss-gain, gain-loss-happy-angry, and loss-gain-angry-happy.

Results

Average emotionality ratings were separately computed for face and point feedback for each participant. Face feedback was rated as significantly more emotional than point feedback, $t(7) = 3.35$, $p = .012$, with average emotionality ratings of 3.37 and 2.76 for face and point feedback, respectively. For younger adults, the average emotionality ratings were 3.45 and 2.57 for face and point feedback, respectively. For older adults the average emotionality ratings were 3.30 and 2.95 for face and point feedback, respectively. Thus, face feedback is rated as more emotionally salient than point feedback for older and younger adults.

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