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DOI
10.1080/13825585.2015.1020917

Publication date
2015

Document Version
Final published version

Published in
Aging, Neuropsychology, and Cognition

Aging, Neuropsychology, and Cognition, 2015
Vol. 22, No. 5, 595–619, http://dx.doi.org/10.1080/13825585.2015.1020917

Routledge
Taylor & Francis Group

Age-related changes in deterministic learning from positive versus negative performance feedback

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(*Received 4 November 2014; accepted 13 February 2015*)

Feedback-based learning declines with age. Because older adults are generally biased toward positive information ("positivity effect"), learning from positive feedback may be less impaired than learning from negative outcomes. The literature documents mixed results, due possibly to variability between studies in task design. In the current series of studies, we investigated the influence of feedback valence on reinforcement learning in young and older adults. We used nonprobabilistic learning tasks, to more systematically study the effects of feedback magnitude, learning of stimulus–response (S–R) versus stimulus–outcome (S–O) associations, and working-memory capacity. In most experiments, older adults benefitted more from positive than negative feedback, but only with large feedback magnitudes. Positivity effects were pronounced for S–O learning, whereas S–R learning correlated with working-memory capacity in both age groups. These results underline the context dependence of positivity effects in learning and suggest that older adults focus on high gains when these are informative for behavior.

Keywords: reinforcement learning; aging; feedback valence; positivity effect; working memory; feedback magnitude; salience

General introduction

The ability to learn from performance feedback declines with age (see, e.g., Chasseigne et al., 2004; Eppinger, Herbert, & Kray, 2010; Hämmerer, Li, Müller, & Lindenberger, 2011; Mell et al., 2005; Pietschmann, Simon, Endrass, & Kathmann, 2008; Simon, Howard, & Howard, 2010; Weiler, Bellebaum, & Daum, 2008). However, the extent of this decline strongly depends on feedback and task details (Eppinger, Hämmerer, & Li, 2011; Hämmerer & Eppinger, 2012), such as whether feedback is deterministic or probabilistic (Eppinger, Kray, Mock, & Mecklinger, 2008; van de Vijver, Cohen, & Ridderinkhof, 2014), whether previous choices have to be taken into account (Worthy, Gorlick, Pacheco, Schnyer, & Maddox, 2011), and whether learning is active or observational (Bellebaum, Rustemeier, & Daum, 2012; Schmitt-Eliassen, Ferstl, Wiesner, Deuschl, & Witt, 2007; Schott et al., 2007).

A key feature of performance feedback is its valence. With age, people generally demonstrate an increased processing bias toward positive over negative information, the so-called "positivity effect" (Reed & Carstensen, 2012). However, research into age-related changes in learning from positive versus negative feedback has yielded mixed results: Older adults indeed learned better from positive than from negative feedback in an

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observational, but not in an active, learning context (Bellebaum et al., 2012; Simon et al., 2010). Instead, in an active learning context, the oldest part of a group of older adults learned better from negative feedback (Frank & Kong, 2008). Relatedly, among individuals with a bias toward learning from negative feedback, this bias was stronger in older compared to young individuals (Eppinger & Kray, 2011). Finally, the increase in switching to the alternative response in older adults compared to young adults was larger after positive than negative feedback, suggesting that positive feedback affected future choices less than negative feedback in the older adults (Hämmerer et al., 2011). Based on these results, two recent review papers on age-related changes in learning and decision making concluded that, depending on the task context, older adults may be biased toward negative rather than positive feedback (Eppinger et al., 2011; Hämmerer & Eppinger, 2012).

However, the task details of the learning tasks applied in these studies raise several issues that may hamper the expression of the positivity effect in feedback learning among older adults. Firstly, all of these studies (Bellebaum et al., 2012; Eppinger & Kray, 2011; Frank & Kong, 2008; Hämmerer et al., 2011; Simon et al., 2010) used probabilistic learning tasks. Yet, older adults are known to be more impaired at probabilistic than deterministic learning (Eppinger et al., 2008; van de Vijver et al., 2014). In probabilistic learning tasks, invalid feedback is presented in a minority of trials: The participant performs the correct response but receives negative feedback, or performs the incorrect response but receives positive feedback. This implies that the participant has to integrate the outcomes of multiple trials featuring the same stimulus to identify the optimal response for that stimulus. This additional level of difficulty in probabilistic learning tasks may influence the weighting and use of positive versus negative feedback by older adults to guide their behavioral adjustments. Indeed, the positivity effect has been demonstrated to decrease or disappear in tasks imposing high processing demands (Reed, Chan, & Mikels, 2014).

Secondly, four of the discussed learning studies (Bellebaum et al., 2012; Frank & Kong, 2008; Hämmerer et al., 2011; Simon et al., 2010) applied versions of the probabilistic selection task (Frank, Seeberger, & O'reilly, 2004). In this task, participants are presented with a pair of stimuli that are shown on the left and the right sides of the screen and are asked to select the stimulus that signals the highest reward by pressing a key on the corresponding side. Thus, the stimulus location and response button are always spatially compatible: To select the left stimulus, the left button has to be pressed, and to select the right stimulus, the right button has to be pressed. This introduces spatial stimulus–response (S–R) compatibility, which has been proposed to lead to "more automatic" responding (Craft & Simon, 1970; Eimer, Hommel, & Prinz, 1995), possibly because a Pavlovian approach toward the rewarded stimulus influences behavior, in addition to instrumental learning performance. This implies that it is impossible to disentangle whether differences in learning from positive versus negative feedback should be attributed to Pavlovian or instrumental learning processes.

Finally, almost all of the discussed studies (Bellebaum et al., 2012; Eppinger & Kray, 2011; Frank & Kong, 2008; Simon et al., 2010) only analyzed learning performance in a final test phase, ignoring possible valence-related differences during the initial learning process.

In the current project, we investigated age-related changes in learning from positive versus negative feedback using deterministic learning tasks, in two studies. In deterministic learning tasks, performance feedback is always valid and outcomes do not need to be combined over multiple trials. Thus, by using deterministic learning tasks, we circumvented the extra difficulty and possible confounds presented by tasks that apply a probabilistic feedback schedule. In line with the positivity effect, we expected older adults to focus more on positive than negative performance feedback during the initial learning process and, thus, to learn the optimal responses faster when receiving positive feedback.

In the first study in this project, we used two instrumental discrimination learning tasks in which a single stimulus was presented in each trial and participants had to learn the correct S–R associations by trial-and-error. Because we presented one stimulus per trial in the center of the screen, the correct button was spatially unrelated to the location of the stimulus. With this design, we therefore avoided possible contributions of Pavlovian approach toward rewarded stimuli and avoidance of punished stimuli (due to spatial S–R compatibility), focusing solely on instrumental learning processes. In the second study in this project, we directly compared the influence of feedback valence on learning in (1) a task in which in each trial a single stimulus was presented and participants had to learn for each stimulus which of two *responses* led to the optimal outcome (S–R association learning, similar to the first study, see also, for example, Haruno & Kawato, 2006; Holroyd & Coles, 2002), and (2) a task in which in each trial two stimuli were presented simultaneously and participants had to learn which *stimulus* led to the optimal outcome (stimulus–outcome (S–O) association learning, similar to the probabilistic selection task of Frank et al., 2004). Because responding toward rewarded stimuli should be more automatic in an S–O learning environment, we hypothesized that older adults would show a stronger bias toward rewarded S–R associations in the S–O compared to the S–R learning environment.

Another key feature of feedback that we explored in the current studies is its magnitude. The valence and magnitude of an outcome are two important determinants of the value attached to the stimulus or response associated with that outcome (Galvan et al., 2005; Smith et al., 2009). Whereas valence is positive or negative, magnitude is thought to contribute to the salience of an outcome (regardless of whether it is positive or negative), and thereby its attentional capture (Anderson, Laurent, & Yantis, 2011; Kahnt, Park, Haynes, & Tobler, 2014; Störmer, Eppinger, & Li, 2014). Indeed, stimuli associated with larger reward magnitudes were selected faster during decision making (Galvan et al., 2005). Moreover, reward magnitude has been shown to be positively related to learning success in both young and older adults (Weiler et al., 2008), although, again, in a probabilistic learning environment.

Thus, in both of our studies, we additionally investigated whether learning from positive versus negative feedback was influenced differently by feedback magnitude in young and older adults. In line with the findings of Weiler and colleagues, we hypothesized that both young and older adults would learn better from large compared to small outcome magnitudes. Additionally, we expected that in older adults, the focus on positive feedback would be even stronger if this positive outcome had a larger magnitude.

Study 1

Introduction

In this first study, participants performed two deterministic, instrumental learning tasks, in which a single stimulus was presented in each trial that had to be paired with a left or right button press. In the first task, only feedback valence was manipulated. In one condition, we applied the feedback schedule that is commonly used in research into age-related differences in reinforcement learning, pairing a correct response with positive feedback and an incorrect response with negative feedback. However, because this schedule does not allow the separate investigation of the contributions of positive and negative reinforcement to learning, we introduced two conditions also comprising neutral feedback. More specifically, in one condition, a correct response led to positive feedback but an incorrect one to neutral feedback, whereas in the other condition, an incorrect response led to negative feedback but a correct response to neutral feedback. In line with our hypothesis that older adults mainly focus on positive feedback, we predicted that they would perform better in the conditions where they could receive positive feedback than in the condition where only negative or neutral feedback could be received.

A similar approach has been applied in two studies by Eppinger et al., (2010, 2013): In a deterministic learning situation, participants had to select the best response for each (single) stimulus based on positive versus neutral or negative versus neutral feedback. In their first study, the authors found no learning differences between positive and negative feedback, although stimuli associated with positive feedback were remembered better in a later memory test (Eppinger et al., 2010). In their second study, the authors showed that older adults only performed worse than young adults in the positive but not in the negative condition (Eppinger et al., 2013). However, in this study, the feedback followed the response after an interval of 3.5–7.5 s. Thus, the S–R combination had to be kept online for multiple seconds. This likely added an additional level of difficulty to the task for the older adults, possibly altering the impact of positive versus negative feedback after this interval. In the current study, stimuli and responses will therefore be followed shortly by the appropriate feedback.

Whereas our first task resembles the initial study by Eppinger et al. (2010), in the second task, we additionally manipulated feedback magnitude. In this task, the choices of participants led to either small or large gains or losses of points. More specifically, we now presented positive and negative feedback in separate blocks. Per block, the outcomes that could be earned were again divided into three conditions. In one condition, one button led to a small win/loss and the other button to neutral feedback. In a second condition, one button led to a large win/loss and the other button, again, to neutral feedback. In a third condition, the two buttons led to a small and a large win/loss, respectively. In line with previous results, we expected both young and older adults to demonstrate better learning in the conditions where large amounts of points could be gained or lost than the condition where only a small or neutral amount of points could be gained or lost. Moreover, for older adults, we predicted that this effect would be stronger for large wins than large losses.

Performance on instrumental reinforcement-learning tasks can be guided either by knowledge of the association between each stimulus and the corresponding correct response, regardless of the exact outcome associated with this response, or by more high-level knowledge of the specific stimulus–response–outcome relations (Daw, Niv, & Dayan, 2005; de Wit & Dickinson, 2009; Dickinson, 1985). To explore whether young and older adults differed in their learning strategy in the current study, we also examined postlearning knowledge of S–R and S–O associations. To assess this, after each block, participants made forced-choice decisions to indicate per stimulus which button represented the correct response (S–R association) and which two outcomes could be acquired when that stimulus was presented (S–O associations).

Material and methods

Participants

Twenty young adults ranging in age from 19 to 31 years (*M* = 21.9, *SD* = 2.7; 10 female; 1 left-handed) and 18 older adults ranging from 68 to 88 years (*M* = 75.0, *SD* = 5.2; 10

female, 2 left-handed) participated in this experiment. Older adults were selected from Seniorlab, a database of older adults interested in participating in psychological research. Participants did not suffer from diagnosed psychiatric or neurological disorders and were not on medication with possible psychotropic effects. Older adults showed no signs of mild cognitive impairment or dementia (Cognitive Screening Test, Deelman, Maring, & Otten, 1989). Participants did not receive financial or other compensation for their participation, although older adults received a small present from Seniorlab. All participants were tested with a laptop, either at home or in a similarly comfortable and quiet environment. All procedures were executed in compliance with relevant laws and institutional guidelines and were approved by the local ethics committee.

Tasks

Task 1.1: the influence of feedback valence on learning. In this task, participants were asked to gain as many points as possible (starting with 0 points), by learning which of two responses (keyboard buttons “Z” and “/”) led to the optimal outcome for each pictorial stimulus using trial-and-error (Figure 1A). Participants were presented with six stimuli per block. Crucially, *within* each block, the six stimuli were organized into three conditions: two stimuli in the “mixed” condition, two stimuli in the “positive” condition, and two stimuli in the “negative” condition (Figure 1B). In the mixed condition, the optimal button press was rewarded with 1 point while the suboptimal button press was punished with the subtraction of 1 point. In the positive condition, the optimal response was still rewarded with 1 point, but the suboptimal response yielded 0 points. Similarly, in the negative condition, the suboptimal response was still punished with the subtraction of 1 point, but the optimal response yielded 0 points. For the two stimuli within each condition, the left button press was the optimal response for one stimulus, and the right button press for the other stimulus.

Participants performed one practice block to familiarize them with the task and make sure they understood the instructions (not included in the analyses), followed by four task blocks. We presented participants with four blocks to acquire a more stable measurement of learning characteristics. It is important to note, however, that although all practice and task blocks featured six new stimuli, the distribution of those six stimuli into the three valence conditions was identical in all blocks (two stimuli in the mixed, two in the positive and two in the negative condition). Per block, each of the six different stimuli was presented 15 times. Every six trials, all stimuli were presented in random order. Stimuli were white-on-black line drawings from the Snodgrass picture set (Snodgrass & Vanderwart, 1980) of concrete objects such as fruits, tools, and vehicles. Stimuli were randomly distributed over blocks and conditions for each participant. Feedback consisted of the number of points that was gained or lost, or the words “too late” if the participant failed to respond within the response window (1500 ms). Task performance did not result in any kind of bonus for the subject.

Before each block, the six stimuli included in that block were shown for familiarization. After each block, we examined the explicit knowledge of S–R and S–O mappings. To this end, all the stimuli from that block were presented consecutively. Per stimulus, the participants first had to indicate what the corresponding optimal button was by pressing the left or right response button (S–R mapping). Subsequently, they had to select with button presses which two outcomes out of the three possible outcomes (+1, 0, −1) could be received when that stimulus was presented (S–O mappings; using keyboard buttons “1”, “2”, and “3”). Note that because participants always had to select two out of the three

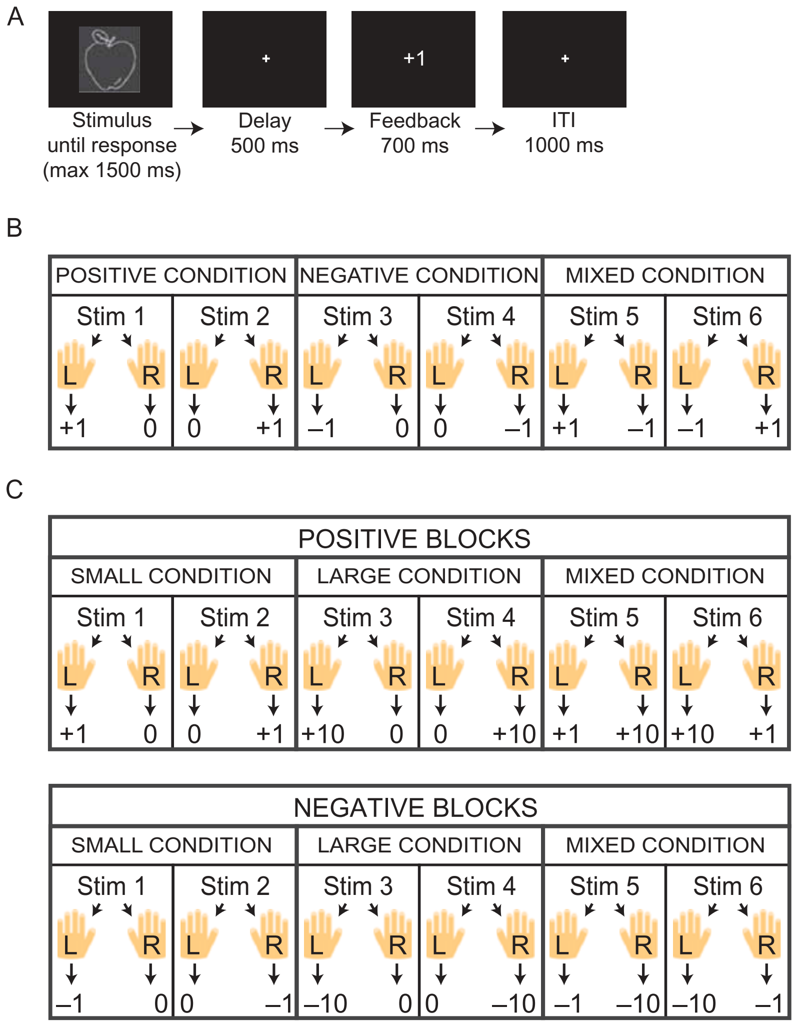

Figure 1. Overview of the tasks and stimulus–response–outcome associations in Study 1. (A) Sequence of events in an example trial of Tasks 1.1 and 1.2. (B) Stimulus–response–outcome associations in Task 1.1 varied within blocks with feedback valence (positive, negative, mixed). (C) Stimulus–response–outcome associations in Task 1.2 varied between blocks with feedback valence (positive, negative), and within blocks with feedback magnitude (small, large, mixed; max = maximum, ms = milliseconds, ITI = inter-trial interval, Stim = stimulus, L = left button press, R = right button press).

possible options, for both the suboptimal and the optimal outcomes, random choice would still lead to the correct selection in 66.7% of the possible combinations.

Task 1.2: the influence of feedback valence and feedback magnitude on learning. The second task was highly similar to the first, but in this task, we also manipulated feedback magnitude. To this end, we created separate blocks with positive or negative feedback (Figure 1C). Within each block, the six stimuli were divided into three feedback magnitude conditions, featuring two stimuli in the "small," two in the "large," and two in the "mixed" condition. Thus, unlike Task 1.1, feedback valence was now manipulated *between* blocks, while feedback magnitude was now manipulated *within* blocks. Again, every six trials, all stimuli were presented in random order. In the positive blocks, the optimal response in the small condition yielded 1 point and the suboptimal response 0 points. In the large condition, the optimal response yielded 10 points and the suboptimal response 0 points. In the mixed condition, the optimal response was rewarded with 10 points and the suboptimal response with 1 point. In the negative blocks, the optimal and suboptimal responses led to 0 and minus 1 points in the small condition, 0 and minus 10 points in the large condition, and minus 1 and minus 10 points in the mixed condition, respectively. Again, within each condition, the left button press was the optimal response for one stimulus, and the right button press for the other stimulus.

Participants performed one positive and one negative practice block. In the real task, three positive and three negative blocks were alternated. Again, multiple blocks were presented to acquire a more stable measurement of learning characteristics, but the feedback magnitude conditions were identical for all positive and all negative blocks, respectively. Whether the first block was positive or negative was counterbalanced over participants. Participants were not informed beforehand whether a block would feature positive or negative feedback. New stimuli were presented in each block, which were not included in Task 1.1. All other task details were the same as in Task 1.1. All participants first performed Task 1.1 and then Task 1.2.

Behavioral analyses

Per task, participants that responded too late in more than 10% of the trials were discarded from the analyses. In Task 1.1, this led to the exclusion of one young and three older adults, and in Task 1.2, no participants met this criterion. Importantly, not excluding any participants for Task 1.1 (and, thus, equalizing the samples for the two tasks) did not change the pattern of results for this task. The average percentages of missed trials in the remaining young participants were 0.67% (SD = 0.88%) in Task 1.1 and 0.39% (SD = 0.44%) in Task 1.2, and in the remaining older participants, they were 3.81% (SD = 2.89%) in Task 1.1 and 3.18% (SD = 2.31%) in Task 1.2. Accuracy was defined as the percentage correct in trials in which participants responded within the response window. As described in the previous section, we examined explicit knowledge of S–R and S–O contingencies after each block. S–R association scores were defined as the percentages of correctly identified optimal responses, whereas S–O association scores were the percentages of correctly identified outcomes, separated for optimal and suboptimal outcomes.

To investigate the effect of feedback valence on learning performance in young and older adults in Task 1.1, accuracy scores collapsed over blocks were entered into a mixed-effects analysis of variance (ANOVA) with factors bin (trial repetitions 1–3, 4–6, 7–9, 10–12, 13–15), feedback valence (positive, negative, mixed), and age (young, old). Thus, for each feedback valence condition, each bin contained 2 stimuli × 4 blocks × 3 repetitions = 24 measurements. Posthoc knowledge of S–R associations in Task 1.1 was assessed by entering scores collapsed over blocks into a mixed-effects ANOVA with factors feedback valence and age, and knowledge of S–O associations by entering scores collapsed over blocks into a mixed-effects ANOVA with factors feedback valence, outcome (optimal, suboptimal), and age. To investigate effects of feedback valence and feedback magnitude on learning performance in young and older adults in Task 1.2, accuracy scores collapsed over blocks per valence condition were entered into a mixed-effects ANOVA with factors bin, feedback valence (positive, negative), feedback magnitude (small, large, mixed), and age. Thus, for each unique combination of feedback valence and feedback magnitude conditions, each bin contained 2 stimuli × 3 blocks × 3 repetitions = 18 measurements. For Task 1.2, we added the factor feedback magnitude to the ANOVAs testing S–R and S–O knowledge.

Greenhouse–Geisser corrections were applied when required, although uncorrected degrees of freedom are reported. Of all ANOVAs, only the highest-order interaction(s) with the variables of interest will be reported in the text. For all results of the ANOVAs, including effect sizes, we refer the reader to Supplementary Tables 1–4. The factor bin was mainly introduced to investigate whether participants improved in performance over trials and, thus, gradually learned the correct responses. We therefore only report significant main effects of bin in the text, and significant interaction effects including the factor bin, if this was the highest-order interaction and the same interaction without bin was not significant (and the interaction with bin therefore provides additional information). This implies that for almost all reported effects, results were pooled over bins and the actual number of measurements per condition was much higher than the numbers described in the previous paragraph. Finally, the analyses that we performed for learning accuracy were also performed for reaction times. These analyses and their results are presented in the Supplementary Material and Methods, the Supplementary Results, and Supplementary Tables 5 and 6.

Results

Task 1.1: the influence of feedback valence on learning

Accuracy. Participants learned the correct choices: accuracy increased over trial bins (Figure 2A; $F(4, 29) = 54.532$, $p < 0.001$). Learning performance differed with feedback valence ($F(2, 31) = 4.770$, $p = 0.018$): Participants performed better in the mixed than in

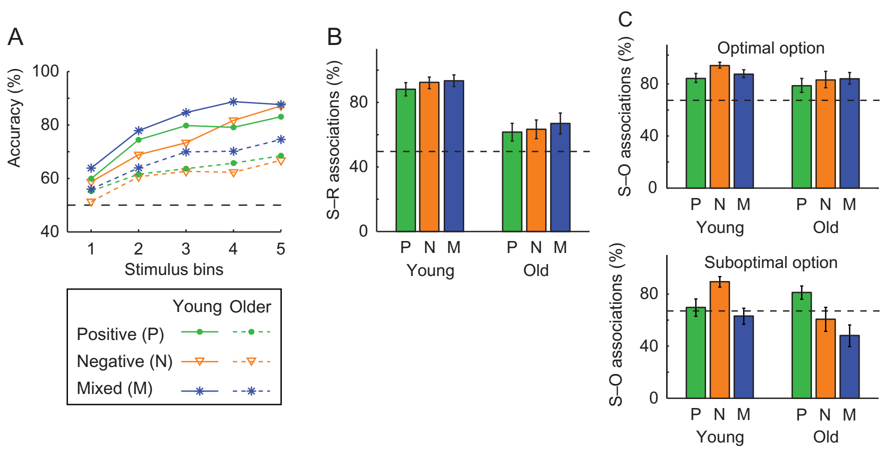

Figure 2. Behavioral performance of young and older adults for different feedback valence conditions in Task 1.1. (A) Average accuracy over stimuli and blocks per stimulus repetition bin as the percentage of correct responses. (B) Average correctly remembered stimulus–response (S–R) associations over blocks. (C) Average correctly remembered stimulus–outcome (S–O) associations over blocks presented separately for the optimal and suboptimal outcomes. Error bars are 1 *SEM*, black dashed lines represent chance level performance (P = positive, N = negative, M = mixed, S–R = stimulus–response, S–O = stimulus–outcome). [To view this figure in color, please see the online version of this journal.]

the positive and negative conditions ($F(1, 32) = 14.330$, $p = 0.001$), but performance did not differ between positive and negative feedback conditions ($F < 1$). Older adults performed worse than young adults ($F(1, 32) = 13.982$, $p = 0.001$), but age did not significantly interact with feedback valence ($F < 1$).

Stimulus–response and stimulus–outcome associations. Older adults learned the correct S–R associations worse than young adults did (Figure 2B, $F(1, 31) = 17.808$, $p < 0.001$), although both age groups performed above chance (young: $t(18) = 11.866$, $p < 0.001$; old: $t(13) = 3.145$, $p = 0.008$). There was no effect of feedback valence ($F(2, 30) = 2.528$, $p = 0.088$) nor an interaction effect between age and feedback valence ($F < 1$) on S–R association knowledge.

Both age groups generally learned the relations between stimuli and outcomes above chance level (Figure 2C; young: $t(18) = 11.120$, $p < 0.001$; old: $t(13) = 3.177$, $p = 0.007$). An interaction effect of age, feedback valence and outcome ($F(2, 30) = 3.859$, $p = 0.026$) indicated that although older adults learned the suboptimal outcomes in the negative condition worse than young adults ($t(18.122) = 3.212$, $p = 0.005$), they learned all the optimal outcomes and the suboptimal outcomes in the positive and the mixed conditions equally well as young adults (p-values > 0.14).

Summary results Task 1.1. Accuracy was lower in older adults than in young adults. Both age groups performed best in the mixed feedback condition, whereas accuracy did not differ between the positive and negative conditions. Finally, the inferior performance of older participants was reflected in their explicit knowledge of S–R contingencies, although they learned most S–O contingencies equally well as young adults.

Task 1.2: the influence of feedback valence and feedback magnitude on learning

Accuracy. In Task 1.2, accuracy also increased over trial bins (Figure 3A; $F(4, 33) = 90.983$, $p < 0.001$). Similar to Task 1.1, learning performance was worse in older than in young adults ($F(1, 36) = 37.899$, $p < 0.001$). In Task 1.2 feedback valence significantly interacted with age ($F(1, 36) = 4.742$, $p = 0.036$): Accuracy was higher for positive than negative feedback in older adults ($t(17) = 2.141$, $p = 0.047$) but not in young adults ($t(19) = -0.110$, $p = 0.913$). Note, however, that the absence of a valence effect in young adults could reflect a ceiling effect and should be interpreted with caution. Performance of the two groups was differently affected by feedback magnitude ($F(2, 35) = 11.652$, $p < 0.001$). Both age groups learned better from large than from small magnitudes (young: $t(19) = -2.806$, $p = 0.011$, old: $t(17) = -4.962$, $p < 0.001$). Additionally, older adults also learned better from mixed than from small magnitudes ($t(17) = -4.590$, $p < 0.001$), and young adults also learned better from large than from mixed magnitudes ($t(19) = -2.764$, $p = 0.012$).

Stimulus–response and stimulus–outcome associations. Postlearning tests indicated that again S–R associations were learned worse by older than young adults ($F(1, 36) = 30.927$, $p < 0.001$), but both age groups performed above chance (Figure 3B; young: $t(19) = 12.130$, $p < 0.001$; older: $t(17) = 3.322$, $p = 0.004$). An interaction of feedback valence and magnitude ($F(2, 35) = 4.492$, $p = 0.020$) showed that S–R associations were learned better for positive than negative feedback when feedback was large ($t(37) = -3.144$, $p = 0.003$), but did not differ

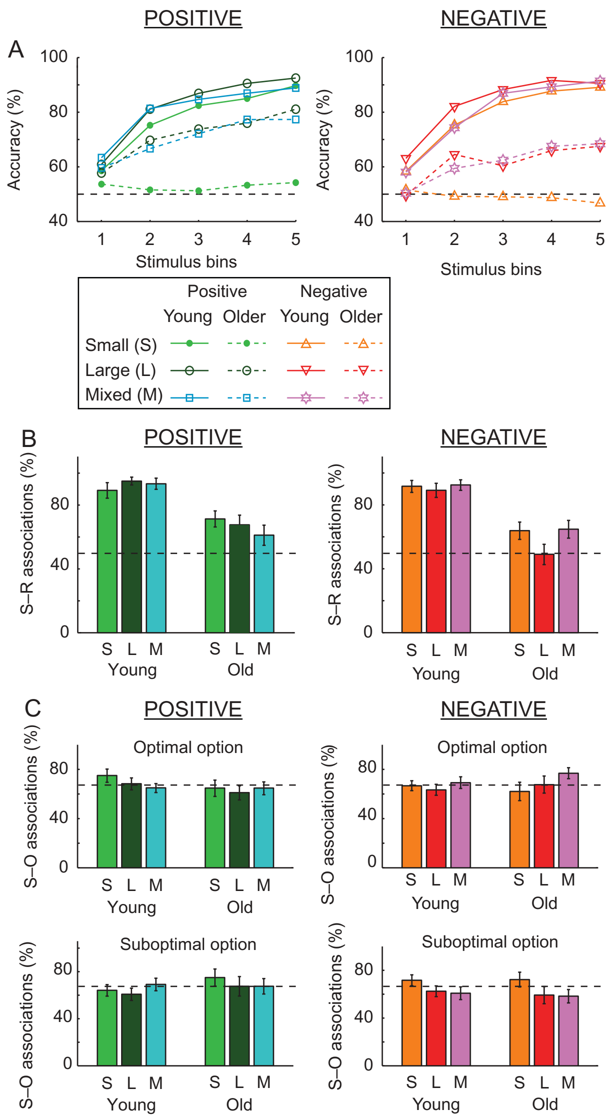

Figure 3. Behavioral performance of young and older adults for different feedback magnitude conditions in positive and negative blocks in Task 1.2. (A) Average accuracy over stimuli and blocks per stimulus repetition bin as the percentage correct responses. (B) Average correctly remembered stimulus–response (S–R) associations over blocks. (C) Average correctly remembered stimulus–outcome (S–O) associations over blocks presented separately for the optimal and suboptimal outcomes. Error bars are 1 *SEM*, black dashed lines represent chance level performance (S = small, L = large, M = mixed, S–R = stimulus–response, S–O = stimulus–outcome). [To view this figure in color, please see the online version of this journal.]

when feedback was small or mixed (small: $t(37) = -0.565$, $p = 0.576$, mixed: $t(37) = 0.433$, $p = 0.668$).

Knowledge of S–O associations did not deviate from chance level in either age group (p's > 0.6), and there were no significant effects of age, feedback magnitude, or feedback valence, or significant interaction effects (Figure 3C).

Summary results Task 1.2. In Task 1.2, older adults again demonstrated lower accuracy scores than young adults. In this task, unlike in Task 1.1, older adults did perform better in the context of positive compared to negative feedback. Whereas both age groups performed better with large compared to small feedback magnitudes, only older adults also performed better for mixed compared to small feedback magnitudes. Participants were also better able to reproduce S–R associations with positive compared to negative feedback when feedback was large or mixed. Young and older adults did not differ in their knowledge of S–O associations.

Discussion

In line with our hypothesis, older adults performed better with positive compared to negative feedback, but only when feedback magnitude was manipulated in Task 1.2. The absence of a valence effect in the young participants could be due to a ceiling effect, as their level of accuracy was generally high. Additionally, performance of both age groups increased as feedback magnitudes (or differences between magnitudes) increased. The comparable behavior of older adults in the large and mixed conditions in Task 1.2 (the two conditions where large magnitudes were involved) seems to indicate that especially this age group was guided by the largest amounts of points that could be gained or lost.

Thus, the results of Study 1 were in line with the positivity effect, when outcome magnitudes were also manipulated. The positivity effect reflects a stronger preference for positive compared to negative information in both attention and memory in older compared to young adults (Reed & Carstensen, 2012). This effect is hypothesized to result from a shift in motivational priorities across the life span depending on life expectancy. As the time that is left for an individual becomes more restricted, the focus is thought to shift to current emotional satisfaction instead of more future-oriented exploration. A processing shift toward positive information would adhere to that focus.

The current appearance of the positivity effect in older adults when feedback magnitudes were also manipulated may be related to an age-related decline in the correct implementation of unexpected feedback. Although the processing of rewards and punishments seems to remain relatively preserved with age (Cox, Aizenstein, & Fiez, 2008; Samanez-Larkin et al., 2007, 2014; Schott et al., 2007), the computation and implementation of prediction errors (PEs, differences between expected and actual outcomes) shows a stronger decline. A combination of direct evidence from computational modeling of the PE and indirect evidence from neuroimaging measures related to the PE suggests that this decline is seen not only after negative (Bellebaum, Kobza, Thiele, & Daum, 2011; Nieuwenhuis et al., 2002; van de Vijver et al., 2014) but probably also after positive feedback (Eppinger et al., 2013; Mell et al., 2009; Samanez-Larkin et al., 2014) and may depend on age-related decreases in dopaminergic transmission in the midbrain and nucleus accumbens (Chowdhury et al., 2013). Thus, PE signals may become less differentiable in older adults, thereby impairing their ability to use feedback for behavioral adjustment. This may explain why older adults in the current study only started to demonstrate a preference for positive outcomes when the difference in magnitudes between these outcomes increased their salience.

Alternatively, the effect of valence in Task 1.2 but not Task 1.1 may have been due to the block-wise presentation of positive and negative feedback in Task 1.2. This presentation schedule implies that per block, participants were either in a loss aversion or gain approach situation. The current results seem to suggest that older adults learn better in a gain approach than a loss aversion context. However, presenting positive and negative feedback in separate blocks may also have made the task less ambiguous, allowing older adults to focus better on the most salient stimuli and outcomes. The fact that older adults ignored the condition with the lowest outcomes in both positive and negative blocks in Task 1.2 seems to support the latter interpretation.

In Task 1.1, participants did not show a difference in accuracy between positive and negative feedback, in line with the results of Eppinger et al. (2010) when using a comparable task. However, participants did perform better in the mixed feedback condition. This condition effect may have partially been due to the unambiguity of both the suboptimal (−1) and optimal (+1) outcomes in this condition. In the other two conditions, an outcome of 0 points could be either optimal (in the negative condition) or suboptimal (in the positive condition) and an extra trial was always required to test the alternative button. Yet, performance of older adults in a similar task did not improve when neutral feedback was colored and therefore unambiguous (Herbert, Eppinger, & Kray, 2011). However, to understand the influence of feedback valence on learning, the comparison between positive and negative feedback conditions is most crucial. In our second study, we therefore excluded the mixed condition.

Study 2

Introduction

In the previous study, participants always had to select the optimal *response* on the basis of the stimulus identity and corresponding outcome (S–R association). However, as mentioned in the "General introduction" section, many studies investigating the effect of feedback valence on learning in healthy aging have used a design in which participants had to select the *stimulus* that was associated with the optimal outcome regardless of the specific spatial (left/right) response (S–O association; Bellebaum et al., 2012; Frank & Kong, 2008; Hämmerer et al., 2011; Simon et al., 2010, but see Eppinger et al., 2010, 2013), possibly introducing biases due to the spatial S–R compatibility. In this second study, we adapted our design to directly investigate whether learning from valenced performance feedback differs between tasks that focus on S–R associations and tasks that require S–O knowledge. Participants (new groups of young and older adults) therefore performed two tasks, one similar to the tasks in the first study (Task 2.1), and a second one in which a pair of stimuli rather than a single stimulus was presented in each trial (Task 2.2). In each pair, one of the stimuli was related to the optimal outcome, the other one to the suboptimal outcome. The stimuli in each pair randomly switched sides in half of the trials. Thus, in this task, participants could not rely on S–R associations, but had to learn which *stimulus* was associated with the best outcome.

Based on the results of our first study, we hypothesized that participants would learn better with large compared to small performance outcomes. Moreover, we expected that older adults would learn better from positive than negative feedback when feedback magnitude was large. Because responding is thought to be more automatized in an S–O learning context, we expected this interaction effect in older adults to be stronger in the S–O (Task 2.2) than the S–R learning task (Task 2.1). Finally, in the first study, explicit knowledge of S–R associations seemed to decrease with age, whereas knowledge of most S–O associations was equal between age groups. Here, we therefore expected learning of S–R associations (Task 2.1) to decline more with age than learning of S–O associations (Task 2.2).

Besides the exclusion of the mixed condition, three other improvements were made to the study and task designs: In the first study, all participants were presented with the two tasks in the same order, so we cannot rule out that feedback valence effects in the second task were influenced by the experiences of participants in the first task. Therefore, task order was now counterbalanced over participants. Additionally, we provided participants with more time to make their response, to ensure that older adults did not underperform because of time pressure. Moreover, the brief delay between response and feedback was removed, to allow for the most direct association between stimulus, response, and feedback.

Material and methods

Participants

In this second experiment, a new group of 28 young and 28 older participants was tested. Because the data of 7 young and 3 older adults were lost due to computer failure, the data of 21 young adults ranging in age from 18 to 26 years (*M* = 22.0, *SD* = 2.8; 13 female; 4 left-handed) and 25 older adults ranging from 69 to 84 years (*M* = 73.4, *SD* = 4.1; 15 female; 2 left-handed) were included. All inclusion criteria and study procedures were the same as in Study 1, but in this study, participants earned a small monetary reward based on their task performance: every 50 points a participant earned was worth € 0.25. This resulted in payments between € 2.50 and € 8.50.

Tasks

Task 2.1: the influence of feedback valence and magnitude on stimulus–response learning. In this first task of Study 2, participants were asked to gain as many points as possible (starting with 0 points), by learning the optimal of two responses for each of eight pictorial stimuli using trial-and-error (Figure 4A). To investigate the influence of both feedback valence and feedback magnitude on learning, these eight stimuli were organized into four conditions, featuring two stimuli per condition (Figure 4B). In the “small positive” condition, the optimal response was rewarded with 1 point, and in the “large positive” condition, the optimal response was rewarded with 10 points. In both positive conditions, the suboptimal response yielded 0 points. In the “small negative” condition, the suboptimal response was punished with a subtraction of 1 point, and in the “large negative” condition, this response was punished with a subtraction of 10 points. In both negative conditions, the optimal response yielded 0 points. Again, within each condition, the left button press was the optimal response for one stimulus, and the right button press for the other stimulus.

Participants performed one block with 30 repetitions of all eight stimuli. Stimulus order was randomized per 16 trials in which all stimuli were presented twice. The same stimulus could never be presented consecutively. 30-s breaks interrupted the task after the 10th and 20th presentations. Again, stimuli were concrete white-on-black line drawings from the Snodgrass picture set (Snodgrass & Vanderwart, 1980). Over participants, stimuli were counterbalanced over tasks (Tasks 2.1 and 2.2) and conditions. Feedback indicated the number of points associated with the chosen response, or “too late” if participants did not respond while the stimulus was presented (2000 ms). Participants received extensive instructions and performed a practice block with 4 (nontask) stimuli that were repeated 30 times. In the practice block, feedback was a green V or red X for correct and incorrect choices, respectively.

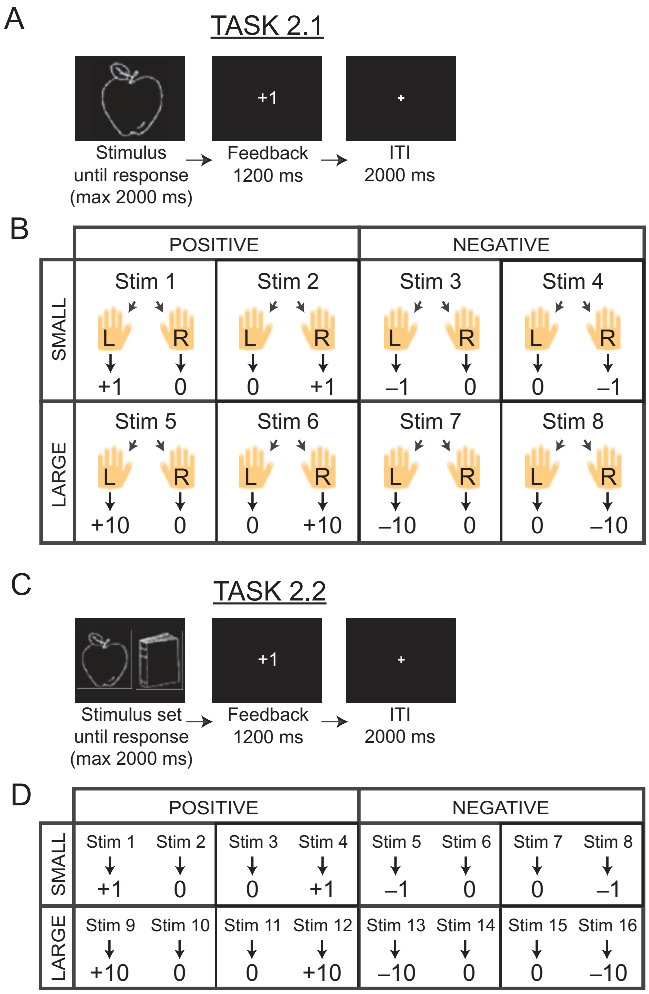

Figure 4. Overview of the tasks and stimulus–response–outcome associations in Study 2. (A) Sequence of events in an example trial of Task 2.1. (B) Stimulus–response–outcome associations in Task 2.1 varied with feedback valence (positive, negative) and feedback magnitude (small, large). Specific stimulus–response associations determined the outcome that was received. (C) Sequence of events in an example trial of Task 2.2. (D) Stimulus–outcome associations in Task 2.2 varied with feedback valence (positive, negative) and feedback magnitude (small, large). The specific stimulus that was selected determined the outcome that was received. Stimuli (and the corresponding correct responses) switched sides in 50% of the trials (max = maximum, ms = milliseconds, ITI = inter-trial interval, Stim = stimulus, L = left button press, R = right button press).

Before the practice and real block, the stimuli included in that block were shown for familiarization. After the real block, participants were again tested on their knowledge of S–O associations. However, we wanted to be able to compare these test scores directly between tasks, and the test as used in Study 1 could not be used for Task 2.2 (see the following section; in Task 2.2, there was no one correct button per stimulus, and single stimuli were only associated with one possible outcome). Therefore, we used a different test design, which was focused more on implicit knowledge of S–O associations. In each trial, combinations of two stimuli were presented above one another. To investigate knowledge of S–O associations, participants were required to indicate for each combination with a button press with which of the two stimuli they could have earned the most or lost the least points (different buttons were used than the response buttons in the task). Every stimulus was paired with all other stimuli except the one from the same condition, so there were six different kinds of choices: large positive-small positive (Pp), large positive-small negative (nP), large positive-large negative (PN), small positive-small negative (pn), small positive-large negative (pN), and small negative-large negative (nN). Because there were two stimuli in each condition, and all combinations were presented twice, participants made 48 choices in total. There was no response deadline in this part.

Task 2.2: the influence of feedback valence and magnitude on stimulus–outcome learning. The design of the second task was the same as that of the first task, but in each trial, a pair of stimuli rather than a single stimulus was presented (Figure 4C). Participants were asked to gain as many points as possible (starting with 0 points), by learning the optimal stimulus in each of eight pairs of pictorial stimuli using trial-and-error. One of the stimuli could be selected by pressing the spatially corresponding button (left button to select left stimulus, right button to select right stimulus). The stimuli in each pair were randomly assigned to the left and right sides of the screen in each trial, with the restriction that they were both presented on each side in 50% of the trials. Importantly, when the stimuli switched sides, the participant still had to press the spatially corresponding button: for example, if the optimal stimulus switched from the left to the right side of the screen, the participant now had to press the right button. Thus, the button that had to be pressed was always spatially compatible with the presentation side of the optimal stimulus.

In each pair, one of the stimuli was related to the optimal outcome, the other one to the suboptimal outcome (Figure 4D). More specifically, in the “small positive” condition, the optimal stimulus signaled a reward of 1 point, and in the “large positive” condition, the optimal stimulus signaled a reward of 10 points. In both positive conditions, the suboptimal stimulus was associated with 0 points. In the “small negative” condition, the suboptimal stimulus signaled a loss of 1 point, and in the “large negative” condition, the suboptimal stimulus signaled a loss of 10 points. In both negative conditions, the optimal response yielded 0 points. Thus, for every stimulus set, one of the stimuli was associated with 0 points, and the other stimulus with a non-zero value (−10/−1/+1/+10). After the task, only the stimuli that were associated with a non-zero value were included in the phase where S–O relations were tested. The order of Tasks 2.1 and 2.2 was counterbalanced over participants.

Tests of intelligence and working memory

Participants performed two tests to investigate the comparability of young and older participants in intelligence and working memory (WM). Fluid intelligence was measured with Raven’s Coloured Progressive Matrices (Raven, Raven, & Court, 2003). Only sets A and B were used, so the total test consisted of 24 items. WM was measured with the Operation Span (O-SPAN, Turner & Engle, 1989) task, in which participants have to remember sets of words of various set lengths, while performing mathematical operations. One older adult did not finish the O-SPAN, so WM scores of only 24 older adults are included. In line with the literature on cognitive aging (see, for example, Bugg, Zook, DeLosh, Davalos, & Davis, 2006; Hedden & Gabrieli, 2004; Sander, Lindenberger, & Werkle-Bergner, 2012), older adults demonstrated lower WM capacities (young: M = 71.57, SD = 13.26; older M = 49.04, SD = 15.08; $t(43) = 5.287$, $p < 0.001$) and lower fluid intelligence scores (young: M = 22.86, SD = 1.15; older: M = 20.72, SD = 3.27; $t(30.806) = 3.048$, $p = 0.005$) than young adults. However, the spread of intelligence scores in young adults was very narrow and many performed at ceiling in the current task, so intelligence scores in this group should be interpreted with caution.

Data analysis

No participants missed more than 10% of trials in either task, so no participants were excluded based on this criterion. The average percentages of missed trials in the young participants were 0.44% (SD = 0.57%) in Task 2.1 and 0.44% (SD = 0.43%) in Task 2.2, and in the older participants, they were 1.55% (SD = 1.43%) in Task 2.1 and 1.41% (SD = 1.43%) in Task 2.2. Again, accuracy was defined as the percentage correct choices in trials in which the participant answered within the response window. The influence of task (and, thus, learning type), feedback valence, and feedback magnitude on accuracy was assessed with a mixed-effects ANOVA with factors Task (2.1, 2.2), bin (trial repetitions 1–6, 7–12, 13–18, 19–24, and 25–30), feedback valence (positive, negative), feedback magnitude (small, large), and age (young, old). Thus, for each unique combination of feedback valence and feedback magnitude conditions in either task, each bin contained 2 stimuli × 6 repetitions = 12 measurements. Learning of S–O relations as measured with the forced choices was quantified as the number of choices for the stimuli in each condition and was assessed with a mixed-effects ANOVA with factors task, feedback valence, feedback magnitude, and age. However, the forced choices after Task 2 were incorrectly registered for one young and eight older adults, which were excluded from this analysis.

Again, Greenhouse–Geisser corrections were applied when required, although uncorrected degrees of freedom are reported. Of all ANOVAs, only the highest-order interaction (s) with the variables of interest will be reported. Again, for almost all reported effects, results were pooled over bins and the actual number of measurements per condition was much higher than was described in the previous paragraph. For all results of the ANOVAs, including effect sizes, we refer the reader to Supplementary Tables 7 and 8. Again, the analyses that we performed for learning accuracy were also performed for reaction times. These analyses and their results are presented in the Supplementary Material and Methods, the Supplementary Results, and Supplementary Table 9.

Results

Performance in Tasks 2.1 and 2.2

Accuracy. Participants generally learned the correct choices: accuracy increased over trial bins (see Figure 5A and B; $F(4, 41) = 204.215$, $p < 0.001$). Performance was higher in Task 2.2 than Task 2.1 ($F(1, 44) = 29.630$, $p < 0.001$). The influence of feedback magnitude and feedback valence varied over tasks and bins (four-way interaction, $F(4, 41) = 2.798$, $p = 0.048$). Posthoc ANOVAs per task with factors feedback magnitude, feedback valence, and bin showed a three-way interaction in Task 2.1 ($F(4, 42) = 3.322$, $p = 0.018$), and an interaction of feedback valence and feedback magnitude in Task 2.2 ($F(1, 45) = 10.711$, $p = 0.002$). Subsequent t-tests demonstrated a dissociation in learning patterns between tasks: Whereas learning was better

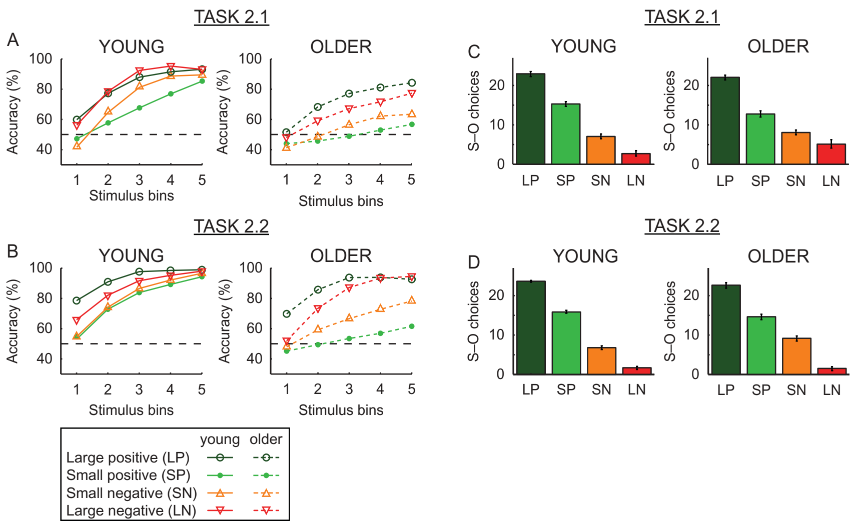

Figure 5. Behavioral performance of young and older adults for different feedback valence and feedback magnitude conditions in Tasks 2.1 (A, C) and 2.2 (B, D). (A and B) Average accuracy over stimuli per stimulus repetition bin as the percentage correct responses. (C and D) Average correctly chosen stimuli related to optimal outcomes during forced choices (stimulus–outcome relations). Error bars are 1 *SEM*, black dashed lines represent chance level performance (S–O = stimulus–outcome, LP = large positive, SP = small positive, SN = small negative, LN = large negative). [To view this figure in color, please see the online version of this journal.]

in Task 2.1 with small negative compared to small positive feedback (in bins 3 and 4; bin 3: $t(45) = -2.611$, $p = 0.012$; bin 4: $t(45) = -2.747$, $p = 0.009$), learning was better in Task 2.2 with large positive compared to large negative feedback ($t(45) = 3.295$, $p = 0.002$).

Older adults learned the correct choices worse than young adults did ($F(1, 44) = 43.186$, $p < 0.001$). Age interacted with feedback magnitude ($F(1, 44) = 7.891$, $p = 0.007$): The impact of large compared to small feedback on performance was larger in older than in young adults (*t*-test comparing age groups on difference scores between large and small: $t(44) = -2.809$, $p = 0.007$). However, given the high accuracy scores in young adults, it is not unlikely that the smaller influence of large feedback on their performance is caused by a ceiling effect.

Knowledge of stimulus–outcome relations in forced choices. Participants were able to differentiate stimuli based on the associated outcome: their choices varied with feedback valence and magnitude (Figure 5C and D; $F(1, 35) = 288.710$, $p < 0.001$). The effects of feedback valence and feedback magnitude differed between Tasks 2.1 and 2.2 (valence: $F(1, 35) = 6.665$, $p = 0.014$; magnitude: $F(1, 35) = 4.932$, $p = 0.033$): The difference in the number of choices for stimuli associated with positive versus negative feedback was larger in Task 2.2 than in Task 2.1 (Task 2.1: $M = 12.68$, $SD = 4.38$; Task 2.2: $M = 14.49$, $SD = 2.92$). The difference in the number of choices for stimuli associated with large versus small feedback was smaller in Task 2.2 than in Task 2.1 (Task 2.1: $M = 2.35$, $SD = 3.58$; Task 2.2: $M = 0.81$, $SD = 2.01$). With optimal performance, the number of choices for large and small feedback would have been equal (the large option was optimal in combinations Pn, Pp, and PN, the small option was optimal in combinations pN, nN, and pn), so performance was again more optimal in Task 2.2 than 2.1. Thus, knowledge of S–O relations was indeed better for the S–O than the S–R learning task. Additionally, knowledge of the difference between stimuli associated with positive versus negative feedback was larger in young than in older adults ($F(1, 35) = 10.311$, $p = 0.003$). There were no higher-order interactions of valence, magnitude, and task or age.

Summary results Study 2. S–O learning (Task 2.2) was generally better than S–R learning (Task 2.1) and identification of the stimulus related to the optimal outcome in a forced-choice situation was also higher after S–O compared to S–R learning. Larger magnitudes were especially beneficial for accuracy in older adults. In both age groups, S–R learning accuracy was higher with small negative compared to positive feedback, and S–O learning with large positive compared to negative feedback.

Relations between learning performance and working memory capacity

In the current study, young participants had higher WM scores than older participants. Moreover, WM load seems to have differed between Tasks 2.1 and 2.2: To make the correct choices, in Task 2.1, the association between a specific picture and a specific outcome had to be learned (e.g., apple = left), whereas in Task 2.2, only the optimal stimulus had to be remembered (e.g., apple). Therefore, we additionally rank-correlated task performance with WM capacity to examine (1) to what extent age-related differences in accuracy could be explained by differences in WM and (2) whether the difference in accuracy between Tasks 2.1 and 2.2 could be explained by a difference in WM load. Because the focus of our studies was on age-related differences in learning from valenced performance feedback, we additionally explored correlations between WM and learning from positive versus negative feedback separately.

WM capacity correlated with performance in Task 2.1 in young (Figure 6A; $r_s = 0.541$, $p = 0.011$) and older adults (Figure 6B; $r_s = 0.544$, $p = 0.006$), but not with performance in Task 2.2 in either group (p-values > 0.07). Within Task 2.1, WM correlated with learning from positive feedback in young adults (Figure 6A; $r_s = 0.491$, $p = 0.024$), and with learning from negative feedback in older adults (Figure 6B; $r_s = 0.544$, $p = 0.006$).

Thus, S–R learning accuracy correlated with WM capacity, and young adults had significantly higher WM scores than older adults. Together, these effects seem to suggest that young adults were better at S–R learning than older adults, but we did not find an interaction effect of age and task on accuracy ($F(1, 44) = 0.780$, $p = 0.382$). To investigate the relation between WM and S–R versus S–O learning accuracy in more detail, we performed a median split on WM scores in both age groups (median young 0.72, median old 0.47, scores could range from 0 to 1), creating four groups: high-WM young adults ($M = 0.83$, $SD = 0.05$, 10 participants), low-WM young adults ($M = 0.61$, $SD = 0.10$, 11 participants), high-WM older adults ($M = 0.61$, $SD = 0.10$, 12 participants), and low-WM older adults ($M = 0.37$, $SD = 0.08$, 12 participants). Note that WM scores were comparable between the low-WM young and the high-WM older adults.

Next, we compared accuracy scores in Task 2.1 (S–R learning) and Task 2.2 (S–O learning) between the groups with t-tests: We expected the group with the highest WM scores to have outperformed all other groups in Task 2.1, and the group with the lowest WM scores to have performed worse than all other groups in Task 2.1. Indeed, young high-WM participants performed significantly better than young low-WM ($t(19) = -3.042$, $p = 0.007$), older high-WM ($t(20) = 4.716$, $p < 0.001$), and older low-WM participants ($t(20) = 6.183$, $p < 0.001$), and older low-WM participants performed significantly worse than older high-WM ($t(22) = -2.640$, $p = 0.015$), young high-WM, and young low-WM participants ($t(21) = 4.078$, $p = 0.001$) in this

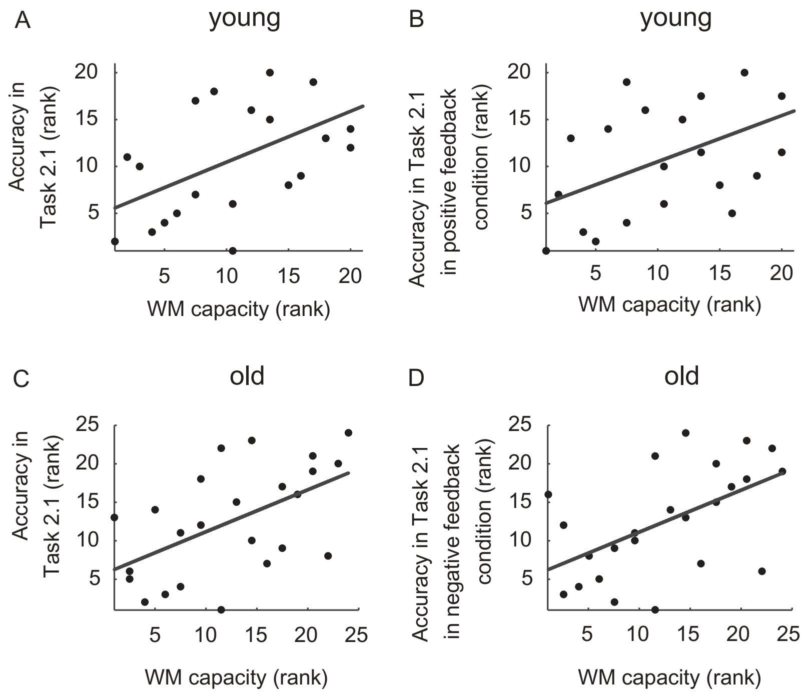

Figure 6. Significant correlations between working memory capacity and stimulus–response learning performance in young (A, B) and older adults (C, D). (A) Spearman rank correlations between working memory (WM) capacity and learning accuracy in Task 2.1 in young adults. (B) Spearman rank correlations between WM capacity and learning accuracy in the positive feedback condition of Task 2.1 in young adults. (C) Spearman rank correlations between WM capacity and learning accuracy in Task 2.1 in older adults. (D) Spearman rank correlations between WM capacity and learning accuracy in the negative feedback condition of Task 2.1 in older adults (WM = working memory).

task. Young low-WM and older high-WM participants, the groups with comparable WM scores, did not significantly differ in accuracy in Task 2.1 ($t(21) = 1.830$, $p = 0.081$). Such a pattern was not seen in Task 2.2: Accuracy scores did not differ between young low-WM and high-WM participants ($t(19) = -0.834$, $p = 0.415$), or between older low-WM and high-WM participants ($t(22) = -1.535$, $p = 0.139$). Thus, on closer examination, WM capacity was indeed related only to S–R learning and may explain age differences therein. The overlap in WM and accuracy scores between age groups may have clouded this effect in our initial ANOVAs.

Discussion

In line with our predictions, participants learned more from large positive than large negative feedback when learning S–O associations. When learning S–R associations, however, participants learned more from small negative than small positive feedback, but there was no difference between large positive and large negative feedback. Additionally, WM capacity only correlated with S–R learning accuracy. Although young adults performed better than older adults, there were no age-related differences in the effects of feedback valence.

Thus, older adults demonstrated significantly better learning from large positive feedback during S–O but not during S–R learning. It is important to note, however, that the pattern of results is numerically the same for S–R and S–O learning in older adults in the current study: In both conditions, accuracy is highest for large positive feedback. This suggests that the positivity effect may also have been present during S–R learning here, but other task aspects such as the high WM load may have decreased the significance of this effect. Indeed, the positivity effect has been demonstrated to decline in tasks imposing high processing demands and individuals with low WM capacity (Mather & Knight, 2005; Reed et al., 2014). In line with this numerically consistent effect, older adults were also most accurate when learning from large positive feedback in Task 1.2 in Study 1, which was in fact an S–R association learning task.

Yet, the difference in significant valence effects between the S–R and S–O tasks in Study 2 suggests that the effect of feedback valence on learning accuracy depends on which kind of associations have to be learned, providing support for the idea that the influence of feedback valence on reinforcement learning is highly task-dependent (Eppinger et al., 2011). Reinforcement learning is generally supported by a large network of frontal and striatal brain areas (for reviews, see, e.g., Maia, 2009; Rushworth, Noonan, Boorman, Walton, & Behrens, 2011). Instrumental (S–R) learning is thought to depend at least partially on learning and decision making processes that are seeded in lateral prefrontal cortex (Amiez, Hadj-Bouziane, & Petrides, 2012; Frank, Moustafa, Haughey, Curran, & Hutchison, 2007; Morris, Dezfouli, Griffiths, & Balleine, 2014). These frontal learning processes have been demonstrated to be highly related to WM: When WM load and the delay interval were independently manipulated in an instrumental (S–R) learning task, both factors explained significant parts of learning success (Collins & Frank, 2012). Indeed, in the current study, only learning in the more difficult S–R learning task correlated with measures of WM capacity in both age groups.

S–O learning accuracy, on the other hand, was not related to WM scores in the current study. The only information that had to be remembered in the S–O learning task was the value of the different stimuli. This was probably less effortful to remember for the participants than the association between a stimulus and a specific response, which may explain why WM capacity was of less importance. Moreover, this type of learning is thought to rely more on the parts of the reinforcement learning network that are involved in the representation of the values of stimuli (rather than actions), such as the nucleus accumbens and orbitofrontal cortex (Grabenhorst & Rolls, 2011; Jocham, Klein, & Ullsperger, 2011; Ostlund & Balleine, 2007).

Thus, the current results suggest that reinforcement learning tasks that capitalize on S–R versus S–O learning may at least partially depend on different learning and brain systems and may therefore capture different aspects of age-related changes in learning. The current, behavioral data do not allow us to disentangle with more specificity which cognitive or brain systems underlie which kind of learning, or how the relative importance and interaction of these systems change with age. Our results suggest, however, that studies specifically designed to answer these questions with neuroimaging methods and/or computational modeling of learning behavior would greatly add to our understanding of why and how age-related changes in reinforcement learning depend on the specific task context.

The current data also cannot speak to the question whether the spatial compatibility between stimulus side and response side in S–O association learning indeed leads to more automatic responding or Pavlovian approach biases, because the optimal stimulus and response sides were always compatible in Task 2.2. A specific examination of the influence of this spatial compatibility on learning success and age-related changes therein is needed to quantify the extent to which this task-design feature affects behavior.

General discussion

The combined results of the current studies demonstrate that older adults indeed learn better from positive than negative feedback, in line with the positivity effect. However, in both studies, this feedback valence effect depended on its magnitude: Older adults learned better from positive compared to negative feedback only when feedback magnitude was also manipulated and they could focus on acquiring large, positive outcomes. This interaction of valence and magnitude, in combination with the lower WM scores of the older adults, suggests that the range of associations that can be acquired simultaneously is more limited in this age group, forcing them to select a subset to learn (first). Indeed, in Task 1.2, older adults did not learn the responses for the stimuli with small outcomes at all, and in Tasks 2.1 and 2.2, there was a large difference between the learning curves of the stimuli with large and small outcomes.

When older adults are (possibly strategically) selecting a subset of associations to learn, they focus on the associations that can win them the most. These large wins would be most salient (similar to large losses, which are learned second-best) and may therefore also trigger the most pronounced PEs. Thus, this initial selection of the most rewarding associations may be explained by the reduced differentiability of PE signals in the aging brain (see “Discussion” section in Study 1). More generally, this may implicate that older adults tend to focus on the stimuli and responses that are most unambiguous and related to the most salient or behaviorally relevant outcomes. Such an explanation could also account for the variability in age-related effects in different behavioral learning studies: which feedback is most salient or relevant can differ between paradigms. The question whether the increase in learning of older adults that is seen with larger magnitudes can be mirrored when outcome salience is increased otherwise, for example, by increasing visual saliency of some outcomes, would make for an interesting follow-up study.

Our results may seem to contradict two recent review papers on age-related changes in learning and decision making (Eppinger et al., 2011; Hämmerer & Eppinger, 2012), which both suggested that older adults show a bias toward negative rather than positive feedback. However, the papers supporting these suggestions (Eppinger & Kray, 2011; Frank & Kong, 2008; Hämmerer et al., 2011; Simon et al., 2010) all employed probabilistic learning tasks, in most cases Frank’s probabilistic selection task (Frank & Kong, 2008; Hämmerer et al., 2011; Simon et al., 2010). As was outlined in “General introduction” section, the probabilistic nature of these tasks, the focus on learning S–O associations (in the probabilistic selection task), and the investigation of postlearning knowledge rather than condition differences during learning may have altered the expression of the positivity effect.

Indeed, both review papers (Eppinger et al., 2011; Hämmerer & Eppinger, 2012) suggested that a bias toward positive versus negative outcomes in older adults may be largely task-dependent, in line with our current results. Eppinger et al. (2011) have suggested that when outcomes are unrelated to subsequent behavior, older adults may focus more on positive outcomes, but when outcomes are important for subsequent actions, negative outcomes are considered of more importance. However, this idea was mainly based on probabilistic learning studies in which only binary feedback was given. In the current tasks, feedback valence and magnitude not only informed the participant about whether behavior was correct, but also signaled the amount of points (and, in the second study, money) that was won or lost. Thus, focusing on the largest outcomes rather than avoiding punishments was more beneficial in the current study.

In both our studies, larger feedback magnitudes were beneficial for both young and older adults, in line with previous results (Weiler et al., 2008). Older adults benefitted more from large feedback than young adults, but this effect is likely caused by a ceiling effect in young adults. Accuracy did not differ between positive and negative feedback in young adults in the first study, whereas it did differ in older adults. In the second study, however, there were no age-related differences in the effects of feedback valence or the interactions with magnitude and learning type on accuracy. This may suggest that in the second study, young adults, like older adults, were presented with too many associations to learn simultaneously and applied a similar selection.

One limitation of our second study is that participants could only win, but not lose, any money. Additionally, in both studies, participants were specifically instructed to gain as many points as possible, rather than to avoid losing any points. Thus, the question remains whether focusing on the positive rather than negative outcomes is something young and older adults always do, or whether this happened either because such a strategy would earn them the most in the current design or because this behavior was enhanced by task instructions.

To conclude, with age, older adults focus more on positive outcomes when these outcomes are large, possibly because they reflect, or are informative to learn, the most appropriate behavior or because they are more salient. This is in line with the positivity effect. Feedback valence effects and learning in general differ depending on whether S–R or S–O associations have to be learned. Because both kinds of tasks are used interchangeably in the reinforcement-learning literature, results should be interpreted and compared cautiously. A direct comparison of the two kinds of learning with computational modeling and brain imaging would provide important information about how subprocesses of S–R versus S–O learning are affected by aging. Future studies should also examine the limitations of the learning capacity of young adults, to test whether they demonstrate the same selection criteria as older adults when they are presented with too many associations to learn simultaneously.

Acknowledgments

The authors thank Mike X. Cohen for helpful comments on a previous version of the manuscript and Wies Goedhart, Bobby Houtkoop, Sophie Knape, Anne Koning, Lot van der Lee, Marieke van Lierop, Leonie Moraal, Merel Richert, Merei Sandbrink, and Jojan Verhorst for their help in data collection.

Disclosure statement

No potential conflict of interest was reported by the authors.

Supplemental data

Supplemental data for this article can be accessed at http://dx.doi.org/10.1080/13825585.2015.1020917.

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