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BRIEF REPORT

Motivational Incentives Modulate Age Differences in Visual Perception

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This study examined whether motivational incentives modulate age-related perceptual deficits. Younger and older adults performed a perceptual discrimination task in which bicolored stimuli had to be classified according to their dominating color. The valent color was associated with either a positive or negative payoff, whereas the neutral color was not associated with a payoff. Effects of incentives on perceptual efficiency and response bias were estimated using the diffusion model (Ratcliff, 1978). Perception of neutral stimuli showed age-related decline, whereas perception of valent stimuli, both positive and negative, showed no age difference. This finding is interpreted in terms of preserved top-down control over the allocation of perceptual processing resources in healthy aging.

Keywords: diffusion model, older adults, reaction time, response bias, valence

Processing of basic visual attributes, such as luminance, color, motion, and depth, deteriorates with age (Faubert, 2002; Schneider & Pichora-Fuller, 2000; Werner & Steele, 1988), reflecting anatomical and physiological changes in visual receptors and in visual pathways in the brain (Spear, 1993; Werner & Steele, 1988). Given that perception involves both bottom-up and top-down influences (Gregory, 1997), it is possible that older adults compensate for sensory deficits by relying more strongly on top-down factors, such as expectation, motivation, and task goals, when they engage in perceptual tasks.

At present, the bulk of the evidence for preserved (or heightened) reliance on top-down processing in aging comes from research on higher-level cognition. In the attentional domain, for example, it has been reported that older adults are as effective as younger adults at using expectancies to optimize visual search performance (e.g., Madden, Whiting, Spaniol, & Bucur, 2005; Whiting, Madden, Pierce, & Allen, 2005). Similarly, top-down regulation of cognitive control in an antisaccade task was found to be equally sensitive to motivational incentives in younger and older adults (Harsay, Buitenweg, Wijnen, Guerreiro, & Richard, 2010). Finally, neuroimaging studies in multiple cognitive domains have shown a "posterior-anterior shift" (Davis, Dennis, Daselaar, Fleck, & Cabeza, 2008), wherein older adults underactivate posterior brain regions and overactivate frontal, and sometimes parietal, regions that are known to support top-down executive control (e.g., Cabeza, et al. 2004; Grady et al., 1994; Madden et al., 1999). This reallocation of processing resources is often—though not always—positively associated with task performance among older adults (e.g., Cabeza, Anderson, Locatore, & McIntosh, 2002; Davis et al., 2008; Grady, McIntosh, & Craik, 2005; Vallesi, McIntosh, & Stuss, 2011; Velanova, Lustig, Jacoby, & Buckner, 2007; but see Colcombe, Kramer, Erickson, & Scalf, 2005; Logan, Sanders, Snyder, Morris, & Buckner, 2002; Morcom, Li, & Rugg, 2007), consistent with a compensatory resource-allocation account (for reviews, see Grady, 2008; Greenwood, 2007).

In recent years, neuroimaging and behavioral work in younger adults, as well as single-cell recordings in monkeys, have documented biasing effects of expectation, motivation, and task goals on early perceptual processes (for reviews, see Heekeren, Marrett, & Ungerleider, 2008; Pessoa, 2009; Summerfield & Egner, 2009; Vuilleumier & Driver, 2007). A detailed discussion of this work is beyond the scope of this paper, but it should be noted that early vision is sensitive to top-down influences, which in turn are mediated by circuits outside the

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visual system (e.g., frontoparietal, cortico-limbic, and cortico-striatal networks).

Despite a wealth of research on emotion, motivation, and reward in aging (for recent reviews, see Charles & Carstensen, 2010; Mohr, Li, & Heekeren, 2010), we are not aware of any prior studies examining the influence of these factors on compensatory resource allocation in older adults during low-level perceptual tasks. As a step towards filling this gap, the current study investigated whether a motivational incentive—payoffs taking the form of the gain or loss of a point—could reduce age differences in a simple perceptual classification paradigm.

The Current Study

To study the effects of motivational incentives on perception in younger and older adults, we used a color discrimination task (Voss, Rothermund, & Brandtstädter, 2008; Ratcliff & Rouder, 1998) in which participants categorized bicolored stimuli according to the dominant color. The difficulty of the perceptual decision was manipulated by varying the color ratio within stimuli. In addition, specific colors were associated with the gain or loss of a point (i.e., a positive or negative incentive) or with no change in points. Each stimulus contained pixels in the gain or loss associated color (henceforth referred to as the valent color), and pixels in the neutral color.

The color classification task offered several advantages in the current context. First, it allowed a high degree of experimental control over the physical properties of the stimuli, which were simple computer-generated images composed of pixels of different colors. Second, using abstract stimuli reduced the likelihood of an Age × Material confound, which can be a concern in the case of semantically rich verbal or pictorial stimuli. Finally, abstract payoffs (gain vs. loss of a point) were chosen to motivate the flexible allocation of processing resources during perception. Point systems have been shown to motivate selective resource allocation in healthy older adults during memory encoding (Castel, Balota, & McCabe, 2009; Castel, Benjamin, Craik, & Watkins, 2002).

Separating Perceptual and Decisional Processes With the Diffusion Model

Performance in a perceptual decision task, such as the color classification task, can be described in terms of speed and accuracy, but these variables do not provide "pure" measures of perceptual processes. To separate perceptual and decisional factors that may be differentially affected by age and motivational incentives, we used a diffusion model analysis (Ratcliff, 1978; for a detailed description of the model, see Ratcliff & Smith, 2004; Ratcliff & McKoon, 2008). Briefly, the diffusion model assumes that during two-choice decisions, information accumulates until a response boundary is reached and the motor response is initiated. Figure 1 illustrates the model applied to the color classification task. Model parameter v, the drift rate, propels a noisy decision process from a starting point (parameter z) toward either of the two boundaries that represent the two responses. In our case, the responses correspond to the valent color (arbitrarily assigned to the upper boundary, parameter a) and the neutral color (arbitrarily assigned to the lower boundary, 0). The stronger the accumulating information, the higher the (absolute) drift rate. The drift rate thus captures the rate of information uptake, or perceptual efficiency.

If the starting point z is closer to the upper boundary, the individual is biased in favor of the valent color; if z is closer to the lower boundary, the individual is biased in favor of the neutral color. The ratio z/a thus provides a convenient measure of response bias, with a value of 0.5 indicating a bias-free observer.

Previous applications of the diffusion model to younger and older adults' performance in perceptual tasks have yielded a mixed

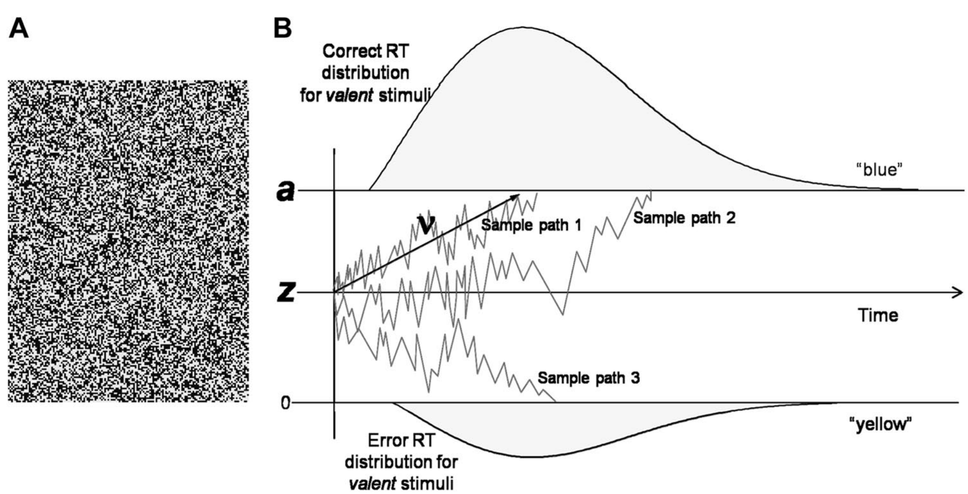

Figure 1. Panel A: Grayscale rendition of a sample blue (52%) and yellow (48%) stimulus. Panel B: Illustration of the diffusion process for the color discrimination task. In the example, blue is the valent (i.e., gain or loss associated) color, and yellow is the neutral color. The diffusion process for blue stimuli starts at point z and is driven towards the upper boundary a by an average positive drift rate, v. The sample paths illustrate within-trial variation in drift, as well as between-trial variation for three trials. Sample paths 1 and 2 result in the correct response ("blue"), whereas sample path 3 drifts towards the lower boundary 0, resulting in an error ("yellow").

picture. Age equivalence in perceptual efficiency was found in a masked brightness discrimination task (Ratcliff, Thapar, & McKoon, 2003) and a signal-detection task (Ratcliff, Thapar, & McKoon, 2001), whereas age-related decline was found for masked letter discrimination (Thapar, Ratcliff, & McKoon, 2003). Importantly, none of these studies used payoffs or other manipulations to bias the allocation of processing resources toward specific stimulus features.

Predictions

In line with previous findings in younger adults (Voss et al., 2008), we expected to find effects of motivational incentives on both response bias (*z/a*) and perceptual efficiency (ν). We further hypothesized that older adults would show reduced perceptual efficiency than younger adults. However, in line with the idea of compensatory top-down allocation of sensory processing resources (e.g., Cabeza et al., 2004; Grady et al., 1994), we predicted that this age-related deficit would be smaller for valent than for neutral stimuli.

Method

Participants

All participants gave written informed consent for the study, which was approved by the ethics committees at Baycrest and Ryerson University. Participants included 27 younger adults (14 women) and 26 older adults (14 women), who were recruited from the local community and received compensation. They reported no major health problems (e.g., history of neurological or psychiatric illness, cancer, cardiovascular disease), had normal or corrected-to-normal vision and hearing, and scored 27 or higher on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975). Additional participant characteristics are shown in Table 1.

Table 1
Participant Characteristics, by Age Group

Characteristic	Younger Adults (N = 26)	Older Adults (N = 27)
Age (years)	22.96 (4.24)	71.50 (6.65)
Age range	18–32	61–85
Education (years)	15.78 (1.99)	16.38 (2.59)
Vocabulary*	17.26 (4.58)	23.56 (3.49)
MMSE	29.41 (.80)	29.0 (1.13)
Neuroticism*	20.11 (7.02)	13.81 (6.67)
Extraversion	30.78 (4.97)	28.23 (7.27)
Openness	32.00 (5.36)	32.08 (6.19)
Agreeableness	31.41 (7.92)	34.88 (5.98)
Conscientiousness	30.70 (6.64)	33.08 (7.62)
Positive mood*	27.11 (6.24)	31.12 (7.65)
Negative mood*	11.59 (2.62)	9.65 (1.29)

Note. Vocabulary = raw score (maximum of 33) on the Mill-Hill Vocabulary Scale (Raven, 1982). MMSE = Mini-Mental Status Examination (Folstein et al., 1975). Neuroticism, extraversion, openness, agreeableness, and conscientiousness = subscales of the Revised NEO Five Factor Inventory (Costa & McCrae, 1989). Positive and negative mood = scores on the Positive and Negative Affect Scale (Watson, Clark, & Tellegen, 1988). Standard deviations are shown in parentheses.
* denotes a significant age group difference, $p < .05$.

Compared with younger adults, older adults scored significantly higher on measures of vocabulary, $t(50) = 5.55$, $p < .01$, $\eta^2 = .38$, and positive mood, $t(51) = 2.09$, $p < .04$, $\eta^2 = .08$, but lower on measures of neuroticism, $t(51) = 3.35$, $p < .01$, $\eta^2 = .18$, and negative mood, $t(51) = 3.39$, $p < .01$, $\eta^2 = .18$.

Design

The design included the between-subjects factor group (younger vs. older) and the within-subjects factors block type (gain vs. loss) and stimulus type (valent, control, and neutral). The following variables were counterbalanced across participants in each age group: the assignment of specific colors (blue, pink, yellow) to each valence (positive, negative, neutral), the assignment of response keys to colors (valent left vs. valent right), and the order of the gain and loss blocks.

Stimuli and Apparatus

Five-hundred forty upright rectangular arrays (150 × 200 screen pixels, subtending approximately 5.11 × 6.81 degrees of visual angle), each containing pixels in two colors, served as stimulus materials. The stimuli were created in MATLAB (Mathworks, Natick, MA).

For *valent stimuli*, pixels in the valent (i.e., gain or loss associated) color outnumbered pixels in the neutral color. The percentage of valent-color pixels was either 54% (30 stimuli) or 52% (30 stimuli). For *control stimuli*, the number of valent-color pixels equaled the number of neutral-color pixels. Each control stimulus was arbitrarily designated as valent (30 stimuli) or neutral (30 stimuli) for purposes of scoring and feedback (see Payoff Structure for details). For *neutral stimuli*, pixels in the neutral color outnumbered pixels in the valent color. The percentage of valent-color pixels was either 46% (30 stimuli) or 48% (30 stimuli).

E-Prime (Psychology Software Tools, Inc.) was used for stimulus presentation and response collection on a 2.8 GHz processor, Pentium 4 laptop computer with a 15-in., flat-panel LCD. Viewing distance was approximately 50 cm. All stimuli were presented centrally against a black background. Instructions, cues, and feedback messages appeared in white 20-point Arial font. Participants pressed the "X" and "," keys with their left and right index fingers to give their responses.

Payoff Structure

Two payoff rules were in effect simultaneously. Stimulus-contingent payoffs were used to assign motivational valence to stimuli. Performance-contingent payoffs were used to encourage participants to maintain a high level of accuracy throughout the task. Stimulus-contingent and performance-contingent payoffs were additive. The specific form of stimulus-contingent and performance-contingent payoffs differed for gain and loss blocks.

In the gain block, the stimulus-contingent payoff rule was that the presentation of a valent stimulus led to an automatic one-point gain, whereas the presentation of a neutral stimulus did not lead to an automatic change in the score. In this way, valent stimuli became desirable. The performance-contingent payoff rule was that each incorrect response was penalized with a one-point deduction.

In the loss block, the stimulus-contingent payoff rule was that the presentation of a valent stimuli led to an automatic one-point loss, whereas the presentation of a neutral stimulus did not lead to an automatic change in the score. In this way, valent stimuli became undesirable. The performance-contingent payoff rule was that each correct response resulted in a one-point reward.

Procedure

Participants were told that their task was to guess which of the two colors was predominant in a series of bicolored stimuli. They were informed that they would start with a score of zero, and that it was important to try to reach the highest score possible. It was explained in detail how the score depended on both the predominant color in each stimulus and on the accuracy of their responses. Participants were naïve to the presence of control stimuli featuring a 50/50 color distribution.

A 15-minute practice task familiarized participants with the task. The instructions were reviewed once again after the practice. The experimental trials were not initiated until the participant demonstrated full understanding of the task.

Each participant completed one gain block and one loss block. With the exception of the payoff rules, gain and loss blocks were structured identically. Each block comprised 12 practice trials and 180 test trials, including 60 valent, 60 control, and 60 neutral trials, which were presented in random intermixed order.

Each stimulus remained onscreen until a response was made, for up to 3 s. During this time, the color names corresponding to the left and right response keys appeared in the bottom left and right corners of the screen, respectively. Following the stimulus presentation, the correct answer was shown for 1 s. In the gain block, incorrect responses were signaled by an additional 1-s feedback screen ("Your answer was incorrect"). In the loss block, correct responses received the additional feedback ("Your answer was correct"). Each trial ended with a 1-s message showing the participant's current score, followed by a 1-s blank screen. After the experiment, participants completed paper-and-pencil questionnaires and were debriefed about the purpose of the study.

Results

Response Probabilities

A mixed ANOVA on the probability of choosing the valent color (see Table 2) revealed significant effects of block type, $F(1, 51) = 7.58$, $p = .008$, $\eta_p^2 = .13$, and stimulus type, $F(2, 50) = 975.57$, $p < .001$, $\eta_p^2 = .98$. These effects were qualified by a significant Block Type × Stimulus Type interaction, $F(2, 50) = 4.84$, $p = .012$, $\eta_p^2 = .16$. Post-hoc pairwise comparisons indicated that for valent and control stimuli, participants were more likely to choose the valent color when it was associated with a positive outcome (gain block) than when it was associated with a negative outcome (loss block), both $t(52) \geq 2.23$, $p \leq .03$, $\eta^2 \geq .11$. In contrast, the probability of choosing the valent color was not significantly affected by block type for neutral stimuli. The Group × Stimulus Type interaction was also significant, $F(2, 50) = 7.15$, $p < .01$, $\eta_p^2 = .22$. Post-hoc pairwise comparisons showed that younger adults were more likely than older adults to choose the valent color in the valent condition, and less likely to choose the valent color in the neutral condition, both $F(1, 51) \geq 5.52$, $p \leq .02$, $\eta_p^2 \geq .10$. There was no significant age difference in the probability of choosing the valent color in the control condition.

Table 2
Means of Behavioral Measures and Diffusion Model Parameters for Younger and Older Adults

Measure and Stim Type	Gain Block		Loss Block	
	Younger	Older	Younger	Older
Behavioral				
P (valent color choice)				
Neutral	.09 (.06)	.18 (.11)	.08 (.07)	.17 (.12)
Control	.53 (.10)	.55 (.11)	.46 (.12)	.48 (.12)
Valent	.92 (.07)	.89 (.08)	.87 (.09)	.85 (.09)
Median RT (ms)				
Neutral	886 (163)	1030 (240)	856 (197)	978 (246)
Control	1065 (241)	1147 (314)	1120 (240)	1177 (302)
Valent	802 (153)	1105 (279)	864 (152)	983 (281)
Diffusion model				
t_0 (ms)	484 (67)	595 (109)	482 (75)	605 (129)
a	1.81 (.39)	1.73 (.45)	1.84 (.39)	1.71 (.45)
z	.99 (.21)	.95 (.38)	.93 (.27)	.83 (.35)
v				
Neutral	−2.29 (.74)	−1.65 (.94)	−2.39 (1.17)	−1.46 (1.14)
Control	0.00 (.42)	.06 (.45)	−.12 (.43)	.06 (.48)
Valent	2.30 (.84)	1.97 (1.25)	2.03 (1.06)	1.88 (.85)
s_t	.18 (.17)	.21 (.15)	.23 (.14)	.27 (.18)
s_z	.31 (.17)	.33 (.24)	.29 (.22)	.19 (.21)
s_v	.68 (.34)	.66 (.42)	.62 (.33)	.56 (.24)
p value	.62 (.23)	.57 (.23)	.44 (.25)	.46 (.25)

Note. Stim Type = stimulus type. *p*(valent color choice) = participants' mean probability of choosing the valent (i.e., gain or loss associated) color. $p < .05$ indicate model misfit. Standard deviations are shown in parentheses.

Response Times

A mixed ANOVA on mean median response times (RTs) (see Table 2) revealed a marginally significant effect of age, $F(1, 51) = 3.99$, $p = .05$, $\eta_p^2 = .07$ that indicated slower responding in older adults. A significant effect of stimulus type, $F(2, 50) = 67.76$, $p < .01$, $\eta_p^2 = .73$, was qualified by a significant Block Type × Stimulus Type interaction, $F(2, 50) = 4.88$, $p = .012$, $\eta_p^2 = .16$. Post-hoc pairwise comparisons showed that participants were slower to respond to valent stimuli associated with a negative outcome than those associated with a positive outcome, $t(52) = 2.15$, $p = .04$, $\eta^2 = .10$. There was no significant effect of block type on responses to neutral and control stimuli.

Diffusion Model Analyses

RTs were excluded from the diffusion analyses if they were either less than 100 ms or greater than 3,000 ms. This affected less than 1% of trials, with no significant differences in the number of excluded trials as a function of age group or block type, all $F\text{s} < 1.0$.

Parameters of Ratcliff's (1978) diffusion model were estimated using the fast-dm method (Voss & Voss, 2007; Voss et al., 2008).

With fast-dm, the model parameters are estimated by optimizing the fit between empirical and predicted cumulative RT distributions using the Kolmogorov-Smirnov (KS) test statistic. Unlike the more widely used chi-square based estimation procedures (Ratcliff & Tuerlinckx, 2002), the KS method does not require binning RTs and thereby ensures maximal information use. This feature of the KS method is particularly valuable when the number of responses per model is small (e.g., if models are fitted individually for each participant).

We estimated separate diffusion models for gain and loss blocks for each participant. For each block type, we further estimated three submodels, corresponding to each of the three stimulus types (neutral, control, and valent). Only the drift rate (ν) was allowed to vary across the three submodels, whereas all other parameters were held constant. As a result, we estimated 18 parameters per participant (nine each for gain and loss blocks): nondecision time (t_0), boundary separation (a), starting point (z), drift for neutral, control, and valent stimuli (ν_{neutral}, ν_{control}, ν_{valent}), variance in nondecision time (s_t), variance in starting point (s_z), and variance in drift (s_ν). The upper decision boundary was associated with valent responses and the lower boundary with neutral responses (see Fig. 1). Positive drift rates were thus expected for valent stimuli, negative drift rates for neutral stimuli.

Model Fit

The *p* value of the KS statistic served as an index of model fit (Voss, Rothermund, & Voss, 2004; Voss & Voss, 2007; 2008). Fit was determined separately for gain and loss blocks, for each participant. Because we estimated three submodels corresponding to the three stimulus types (neutral, control, and valent) for each block type, the product of the *p* values of the KS statistic for the three submodels served as a fit index for each combination of participant and block type. A significant result ($p < .05$) signaled model misfit. This was the case, in the loss block, for two younger adults. The pattern of statistical significance did not change when we excluded these individuals from the analyses; therefore, the results presented here include all participants (see Table 2).

Model Parameters

Response bias (*z/a*). A mixed ANOVA with factors group and block type yielded a significant effect of block type, $F(1, 51) = 5.77$, $p = .02$, $\eta_p^2 = .10$. Younger and older participants were significantly biased in favor of the valent color when it was associated with a positive incentive (gain block), $t(52) = 3.29$, $p < .01$, $\eta^2 = .26$, but showed no bias when it was associated with a negative incentive (loss block), $\eta^2 < .01$ (see Figure 2).

Drift rate (ν). A mixed ANOVA with factors group, block type, and stimulus type revealed a marginally significant effect of group, $F(1, 51) = 3.91$, $p = .05$, $\eta_p^2 = .07$, and a significant effect of stimulus type, $F(2, 102) = 421.53$, $p < .01$, $\eta_p^2 = .89$. These effects were qualified by a significant Group × Stimulus Type interaction, $F(2, 102) = 7.22$, $p < .01$, $\eta_p^2 = .12$, illustrated in Figure 2. Post-hoc pairwise comparisons revealed a significant age effect on drift for neutral stimuli, $F(1, 51) = 12.10$, $p < .01$, $\eta_p^2 = .19$, reflecting age-related decline in perceptual efficiency for these materials. In contrast, drift rates for control and valent stimuli showed no significant age effects, both $\eta_p^2 \leq .03$.

One potential concern with the drift rate analysis is that the effects of age and stimulus type may reflect differences in drift rate bias (Ratcliff, 1985), rather than differences in perceptual processing. In the current context, drift rate bias would be present if drift rates for the color-balanced control stimuli deviated from zero. A series of one-sample *t*-tests for each age group and block type suggested that drift rates for control stimuli were not significantly different from zero, all ts < 1.0. We nevertheless conducted an additional analysis in which we subtracted the control-stimulus drift rates from the drift rates for neutral and valent stimuli, respectively. An ANOVA on these "bias-corrected" drift rates with factors group (younger vs. older), block type (gain vs. loss), and stimulus type (neutral vs. valent) yielded the same pattern of results as the ANOVA on noncorrected drift rates, supporting an interpretation of the results in terms of perceptual processing differences rather than differences in drift rate bias. Finally, the drift rate pattern did not change when positive mood, negative mood, or neuroticism (all of which showed significant age differences; see Participants) were included as covariates.

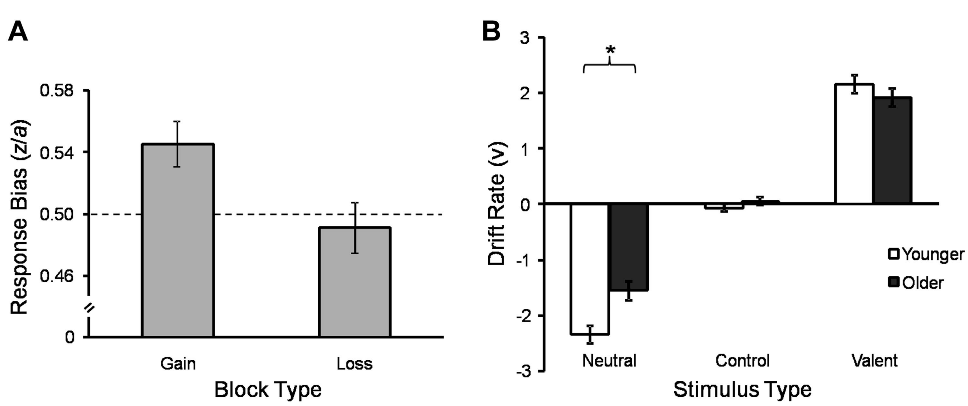

Figure 2. Panel A: *M* parameter estimates for response bias (*z/a*), collapsed across the two age groups. The dotted line indicates absence of response bias; values above the line indicate a bias to respond with the valent color, values below the line indicate a bias to respond with the neutral color. Panel B: *M* parameter estimates for drift rate (ν), collapsed across gain and loss blocks. Error bars represent standard errors.

Other parameters. Two-way mixed ANOVAs with factors group and block type on the other parameters (t_0, s_t, s_z, and s_v) revealed only two significant effects. First, as is typically observed, the mean nondecision RT (t_0) was longer for older adults (M = 600 ms) than for younger adults (M = 483 ms), $F(1, 51) = 24.42$, $p < .001$, $\eta_p^2 = .32$. Second, starting point variability (s_z) was marginally higher in the gain block than in the loss block, $F(1, 51) = 4.23$, $p = .05$, $\eta_p^2 = .07$.

Discussion

Consistent with some previous findings in the literature on aging and perception (for reviews, see Faubert, 2002; Schneider & Pichora-Fuller, 2000; but see Ratcliff et al., 2001, 2003), older adults in this experiment showed reduced perceptual efficiency, as indexed by the drift rate parameter of the diffusion model, than younger adults. However, as hypothesized, this age-related deficit was significantly reduced, to a point where the age difference was no longer statistically significant, for valent stimulit—those which signaled receipt of a positive (gain of a point) or negative (loss of a point) outcome. To our knowledge, this is the first demonstration of incentive-based modulation of age differences in visual perception. It nicely adds to the existing literature on compensatory resource allocation in aging, which has largely focused on attention, executive control, and memory (e.g., Cabeza et al., 2004; Grady et al., 1994; Madden et al., 1999). Our findings lend support to the idea that preserved motivational mechanisms may help older adults to compensate for losses in neurocognitive efficiency "when it matters most," consistent with Baltes & Baltes' (1990) selection, optimization, and compensation framework (see also Lindenberger & Baltes, 1994).

Applying the diffusion model (Ratcliff, 1978) allowed us to distinguish between response bias and perceptual facilitation. Both age groups showed an "optimistic" response bias, similar to the findings reported by Voss and colleagues (2008). Effects of emotional valence on response bias have been found in other domains (e.g., Spaniol, Voss, & Grady, 2008), but none of these studies has indicated that the interaction of age and emotion effects on cognitive performance are *solely* driven by age differences in response bias.

Our data do not speak directly to the mechanisms underlying the incentive effect of age differences in perceptual efficiency. However, recent advances in cognitive neuroscience (for reviews, see Heekeren et al., 2008; Pessoa, 2009; Summerfield & Egner, 2009; Vuilleumier & Driver, 2007) suggest that anticipation of positive or negative consequences associated with particular stimulus dimensions may prime early processing in the ventral visual pathway in a top-down fashion. Our findings suggest that these facilitatory mechanisms may be preserved in aging. By the same token, the results imply that age differences in the perception of neutral stimuli may partially result from age differences in the allocation of processing resources. This, in turn, suggests that age-related perceptual losses are not "set in stone" but may be sensitive to training and plasticity—a possibility that highlights the need for future research on aging and low-level perception, using both behavioral and neuroimaging methods.

Positive and negative incentives had equally enhancing effects on perception in older adults. At first glance, this finding is inconsistent with reports of the age-related "positivity effect" sometimes reported in the domains of attention, memory, and choice (for a review, see Mather & Carstensen, 2005). According to the positivity effect, one would expect to see greater perceptual enhancement for positive compared with negative stimuli. Leaving aside the possibility that the positivity effect may not be a universal phenomenon (e.g., Murphy & Isaacowitz, 2008), its absence in the current study could indicate that abstract incentives (gains and losses of points) do not produce a strong emotional response. It would be useful, in this regard, to examine whether emotional stimuli (e.g., faces, scenes, or words) would produce a different pattern of results.

Our findings seem to contradict recent evidence of reduced dopaminergic function (for a review, see Mohr, Li, & Heekeren, 2010) and reduced sensitivity to loss signals in aging (e.g., Nielsen, Carstensen, & Knutson, 2008; Samanez-Larkin, et al., 2007). We found no evidence for an age difference in sensitivity to negative incentives, perhaps because we used symbolic incentives (gains and losses of points). Whether a gain-loss asymmetry would emerge with a stronger manipulation of the reward system (e.g., pleasant vs. aversive tastes, monetary gains vs. losses) is a question for future research.

A final observation we wish to make is that participants' goal in this study was to maximize points. From the participants' perspective, improved perceptual performance for valent stimuli was instrumental for reaching the highest possible final balance. The general implication of the current findings for cognitive aging research may be that understanding the true limits of the aging perceptual and cognitive systems requires understanding of the aging motivational system (see also Carstensen, Mikels, & Mather, 2006; Hess, 2005).

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