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Uncertainty drives exploration of negative information across younger and older adults

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Abstract

Although individuals generally avoid negative information, recent research documents that they voluntarily explore negative information to resolve uncertainty. However, it remains unclear (a) whether uncertainty facilitates exploration similarly when exploration is expected to lead to negative, neutral, or positive information, and (b) whether older adults seek negative information to reduce uncertainty like younger adults do. This study addresses the two issues across four experimental studies ($N = 407$). The results indicate that individuals are more likely to expose themselves to negative information when uncertainty is high. In contrast, when information was expected to be neutral or positive, the uncertainty surrounding it did not significantly alter individuals' exploration behavior. Furthermore, we found that uncertainty increased the exploration of negative information in both older and younger adults. In addition, both younger and older adults chose to explore negative information to reduce uncertainty, even when there were positive or neutral alternatives. In contrast to the age-related similarities in these behavioral measures, older adults demonstrated reduced scores in questionnaires on sensation seeking and curiosity, relative to their counterparts who were younger. These results suggest that information uncertainty has a selective facilitation effect on exploration for negative information, and that normal aging does not alter this tendency, despite age-related reductions in self-reported measures of personality traits relevant to information seeking.

Curiosity is a fundamental motivation for human beings to explore novel situations and learn new information (Kashdan & Silvia, 2009; Murayama et al., 2019). It plays key roles in predicting academic performance (Raine et al., 2002; Von Stumm et al., 2011), maintaining individuals' wellbeing (Kashdan & Steger, 2007), and preventing diseases (Richman et al., 2005). However, curiosity may come at a cost. As represented in the tale of Pandora's box, people sometimes have a strong curiosity to resolve uncertainty, which can lead them to expose themselves, even deliberately, to aversive information (FitzGibbon et al., 2021; Hsee & Ruan, 2016; Lau et al., 2018; Niehoff & Oosterwijk, 2020). However, it is hitherto unclear whether one's desire to explore information to resolve uncertainty is particularly present when the information is expected to be negative. It is also unknown whether older and younger adults expose themselves to negative information to resolve uncertainty in similar ways. The present study attempts to resolve these issues.

In recent years, studies have demonstrated that people deliberately seek negative information to satisfy their curiosity (i.e., morbid curiosity; Bench & Lench, 2019; Menninghaus et al., 2017; Oosterwijk et al., 2020; Redmond et al., 2019). In one study (Oosterwijk, 2017), for example, participants were shown two images simultaneously (one negative social image and one neutral image) for 2 s and asked to select one of them for an additional 4 s of viewing. The results indicated that participants were more likely to select negative social images (e.g., images of social conflicts) compared to their neutral counterparts. In addition, their choice to select negative images was significantly correlated with their subjective feelings of interest (which is closely related to curiosity). These results thus suggest that people seek negative information to satisfy their curiosity (see Redmond et al., 2019 for similar findings).

One factor that is known to facilitate morbid curiosity is uncertainty of outcomes (Niehoff & Oosterwijk, 2020). Accumulative research has shown that individuals express stronger curiosity towards outcomes when these outcomes are uncertain than when they are certain (van Lieshout et al., 2018). Such effects of uncertainty on information seeking are also observed even when outcomes are negative. For example, Hsee and Ruan (2016) presented participants with a covered image of a negative and disgusting insect. They then asked the participants to indicate whether they wanted to view or skip the image. Half of the participants were provided the name of the insect along with the covered image (a certain condition), whereas the other half were simply shown a question mark and not told the name of the insect (an uncertain condition). The authors found that participants viewed images of negative insects more when the outcomes were uncertain rather than certain, suggesting that people have a desire to resolve uncertainty, even when it leads to negative outcomes.

However, it remains unclear if outcome uncertainty has similar facilitation effects on exploration, irrespective of outcome valence. In fact, the extant literature is inconclusive regarding how valence modulates the effects of uncertainty on exploration behavior. More specifically, some researchers have posited that curiosity can be stronger for negative information than for positive or neutral information; given that the former tends to deviate from the norm (Niehoff & Oosterwijk, 2020; Oosterwijk et al., 2020; Somerville & Whalen, 2006; Tamai et al., 2023). According to this view, uncertainty should increase exploration largely for aversive outcomes than for neutral or positive ones. In contrast, other theories and studies have suggested that the utility of information is enhanced by positive valence (Charpentier et al., 2018; Golman & Loewenstein, 2018; Kobayashi et al., 2019). These

results suggest the alternative possibility that the effects of uncertainty on exploration are weaker when anticipated outcomes are negative than neutral or positive.

Furthermore, previous research on morbid curiosity has predominantly focused on younger adults (but see Grisanzio et al., 2021 for children and adolescents). Therefore, it is unknown whether outcome uncertainty has facilitative effects on the exploration of negative information throughout the adult lifespan. Past studies on self-reported personality measures for assessing curiosity or related concepts (such as sensation seeking and openness to experiences) have revealed that as individuals grow older, they show reduced levels of curiosity and reduced tendencies to explore novel situations (e.g., Chu et al., 2020; Robinson et al., 2016; for a review see Sakaki et al., 2018). Older adults also show reduced exploration behavior in laboratory tasks (Mata et al., 2013). Additionally, regions of the brain, which are implicated in curiosity, are susceptible to age-related decline (Sakaki et al., 2018). Specifically, while curiosity is typically associated with the striatum and the dopaminergic systems in younger adults (e.g., Gruber et al., 2014), normal aging leads to a loss of dopamine neurons (for a review see Düzel et al., 2010). Taken together, these results suggest that older adults show lower levels of desire to resolve uncertainty, irrespective of whether the expected outcomes are negative or neutral.

Alternatively, another line of research has demonstrated that older adults preferentially process positive stimuli over negative stimuli, relative to younger adults (the age-related positivity effect; for reviews see Mather, 2016; Nashiro et al., 2012; Reed et al., 2014). This positivity effect has been explained by the socioemotional selectivity theory, which posits that as individuals get older, they tend to focus more on emotion regulation goals than information seeking goals (Carstensen et al., 1999). If older adults focused on

emotional meaning and satisfaction more than information seeking, as suggested by the socioemotional selectivity theory, they would not expose themselves to negative outcomes even in the presence of uncertainty. Thus, an alternative prediction is that older adults, relative to younger adults, show reduced effects of uncertainty on the exploration of outcomes, especially when they expect negative outcomes.

The present study aims to address two main issues: (1) How outcome valence modulates the effects of uncertainty on exploration; and (2) How old age modulates the interaction between valence and uncertainty in exploration. Regarding the first question, given the varied findings in the literature (as described above), we did not set a clear hypothesis regarding the interaction between uncertainty and valence, even in younger adults. Regarding the second question, we tested the two aforementioned possibilities: (1) Age-related reduction in the effects of uncertainty irrespective of the expected outcome's valence; or (2) Age-related reduction in the effects of uncertainty, especially when expecting aversive outcomes. In Study 1, we establish an experimental paradigm to examine whether outcome uncertainty has similar effects on exploration of negative vs. neutral outcomes in younger adults. In Study 2, we extend Study 1 by examining whether older and younger adults show similar vs. different effects of outcome uncertainty across exploration of negative vs. neutral outcomes. In Studies 3–4, we introduce positive, negative, and neutral outcomes and examine whether outcome uncertainty leads younger vs. older adults to expose themselves to negative outcomes despite a positive/less negative alternative.

Study 1

Study 1 included only younger adults and aimed to establish an experimental paradigm which would be subsequently used to examine the interaction across participants'

age, outcome valence, and outcome uncertainty on information seeking. We used a variant of the insect card task proposed by Hsee and Ruan (2016) with the following modifications (Figure 1). First, we included negative and neutral outcomes, resulting in four conditions: uncertain-negative, certain-negative, uncertain-neutral, and certain-neutral. Second, as it was difficult to find neutral insects, we included both insects and animals as stimuli. Third, to ensure that participants perceived animals in the negative condition as more negative than those in the neutral condition, we asked participants to rate each animal's valence at the end of the study.

Fourth, we changed the cues shown in the uncertainty condition. In the certain condition, participants were shown the name of the insect/animal in the image, as done by Hsee and Ruan (2016; e.g., “Mosquito”). Thus, participants were able to predict the identity of the concealed animal/insect, as well as its valence. Conversely, in the uncertain condition, the covered image was shown, along with the name of a different animal/insect that represented the same valence (e.g., “Something like (but not) a mosquito”); participants were told that the concealed image included an animal with a similar level of valence to the one indicated on the label. Thus, in the uncertain condition, participants were able to identify the valence of the concealed animal/insect and the animal that they would not see, but not the exact identity of the concealed animal/insect (e.g., an image of a cockroach was shown after the cue “Something like (but not) a mosquito”). This manipulation allowed us to increase uncertainty in one of the two conditions while maintaining similar emotional responses to the covered images (i.e., cues) across both conditions (e.g., in both the certain and uncertain conditions, participants were shown the names of animals with negative valence during the initial cue presentation, which could have induced emotional responses).

Methods

Participants and Design

Thirty-five Japanese undergraduate students participated in the experiment (see Table 1 for demographic information). They were paid 1,000 JPY/hour for their time. The sample size was determined to ensure a statistical power of 80% to detect the effects of uncertainty on negative outcomes observed in the previous study (Hsee & Ruan, 2016). The experiment had four within-participant conditions based on a 2 (uncertainty: certain vs. uncertain) \times 2 (valence: negative vs. neutral) design.

Materials

Twenty animals (10 negative and 10 neutral; see Appendix 1) were used in the study; for each valence, five of them were used in the certain condition and the remaining five in the uncertain condition. Condition assignment was counterbalanced across participants. Images of animals were obtained from the International Affective Picture System (Lang et al., 2008), the Nencki Affective Picture System (Marchewka et al., 2014), the Open Affective Standardized Image Set (Kurdi et al., 2016), as well as the Internet. Prior to Study 1, six older and five younger adults, who did not partake in any other studies reported in this manuscript, rated the names and images of 60 animals. The 20 animals and stimuli were chosen based on this pilot study's ratings (see Supplementary Materials for details).

Choice Task

The task was designed and modified based on Hsee and Ruan's (2016) approach. In each trial, participants were shown a rectangle representing a covered image (Figure 1). In the certain condition, the covered image was accompanied by the name of the animal that

was subsequently shown (e.g., “Crab”). In contrast, in the uncertain condition, the covered image was accompanied by the name of a different animal representing the same valence (e.g., “Something like (but not) a mosquito”). These cues were shown in red and green for the negative and neutral conditions, respectively.

During the cue presentation, participants were asked to press the “k” key if they wanted to see the image and the “d” key if they did not. When they chose to see the image, the covered image was replaced by an image which was shown for 3 s. In the negative condition, cues were always followed by an image of a negative animal, whereas in the neutral condition, cues were always followed by an image of a neutral animal. When participants chose not to see the image, they were shown a blank screen for 3 s instead of the outcome image. This interval was included to ensure that the study duration would be similar irrespective of participants’ choice.

One hundred trials were conducted (25 trials per condition). In each condition, the five animals were repeated five times each, with a different outcome image. The order of the 100 trials was randomized for each participant, irrespective of conditions. Prior to the task, participants were informed that the animal names printed in red were emotionally negative and those in green were emotionally neutral.

Procedure

After providing consent, participants completed questionnaires on curiosity and information-seeking behavior, including the Brief Sensation Seeking Scale (BSSS; Hoyle et al., 2002), the Curiosity and Exploration Inventory (CEI-II; Kashdan et al., 2009), and the Japanese Epistemic Curiosity Scale (JECS; Nishikawa & Amemiya, 2015), which was developed based on the Epistemic Curiosity Scale (Litman & Spielberger, 2003) and included

two dimensions: specific curiosity vs. diverse curiosity. To examine the effect of seeing negative animals on participants' moods, they also completed the Positive and Negative Affect Schedule (PANAS; Time 1; Watson et al., 1988). They next performed the main choice task, following which they completed the PANAS again (Time 2). The valence rating task was subsequently performed, wherein participants rated the name of each animal in terms of its valence level (1: extremely negative – 9: extremely positive). Participants also completed the State-Trait Anxiety Inventory (STAI; Spielberger et al., 1970) and the Center for Epidemiologic Studies Depression Scale (CES-D; Radloff, 1977) for purposes not relevant to the present study (thus the results will not be discussed).

Results

All analyses (across Studies 1–4) were performed using R (ver 4.1.2); Analyses of variance (ANOVAs) were performed using the “afex” package (Singmann et al., 2015) and figures were created using the ‘ggplot2’ package (Wickham et al., 2016). The means and standard deviations (SDs) for the self-report questionnaire are presented in Table 1. The PANAS results are reported in Supplementary Materials, as they are not the present study's primary focus. Confidence intervals (CI) were reported at 95%.

Valence Ratings

The animal names used in the negative condition were rated more negatively than those used in the neutral condition ($M_{neg} = 2.71$, $SD = 1.26$, $M_{neu} = 6.25$, $SD = 1.11$), $F(1, 34) = 323.43$, $\eta^2_G = .69$, $p < .001$.

Effects of Uncertainty and Valence on Choice

To examine the effects of uncertainty and valence on participants' choices, a 2 (valence: negative vs. neutral) \times 2 (uncertainty: certain vs. uncertain) ANOVA was

performed on the participants' decision to view images during the choice task (Figure 2A).

This ANOVA revealed a significant main effect of valence, $F(1, 34) = 76.87, p < .001, \eta^2_G = 0.38$, indicating that participants viewed images more frequently in the neutral condition ($M = .88, SD = 0.22$) than in the negative condition ($M = .40, SD = 0.39$). Thus, they chose to see negative stimuli less frequently than neutral images, which is consistent with past findings indicating that individuals seek negative information less than non-negative information (Charpentier et al., 2018; Kobayashi et al., 2019). There was also a significant main effect of uncertainty, $F(1, 34) = 5.72, p = .02, \eta^2_G = .018$, indicating that participants chose to view images more frequently in the uncertain condition ($M = .68, SD = 0.39$) than in the certain condition ($M = .60, SD = 0.40$). These main effects were also qualified by a significant valence-by-uncertainty interaction, $F(1, 34) = 5.18, p = .029, \eta^2_G = .009$. Follow-up simple effect tests revealed that the effects of uncertainty were significant in the negative condition ($M_{certain} = .32, SD = 0.35; M_{uncertain} = .47, SD = 0.41$), $t(34) = -2.95, d = 0.50, p = .01$, CI for the mean difference ($CI_{diff} = [.04, .24]$), but not in the neutral condition ($M_{certain} = .87, SD = .21; M_{uncertain} = .89, SD = .23$), $t(34) = -0.60, d = 0.10, p = .55, CI_{diff} = [-.05, .10]$, indicating that outcome uncertainty selectively enhanced exploration for aversive outcomes (Figure 2B). We also computed correlation between the scores of self-report questionnaires on curiosity and participants' choice for negative outcomes under uncertainty but none of these were significant ($ps > .05$) with False Discovery Rate (FDR) correction.

Discussion

In Study 1, we found that younger individuals explored information more in the uncertain condition than in the certain condition. Additionally, this tendency was more pronounced for a negative outcome than for a neutral outcome, despite the general preference

for neutral images over negative images. These results suggest that individuals are more keen to resolve uncertainty when the expected outcomes are negative rather than neutral.

Study 2

Study 2 aimed to extend Study 1 by addressing whether the effects of outcome uncertainty on exploration differ between younger and older adults. As described in the introduction, if older adults show general reduction in exploration and curiosity (Mata et al., 2013; Robinson et al., 2016), they would show reduced effects of uncertainty on the exploration irrespective of the valence of outcomes. In contrast, if older adults have stronger emotion regulation goals than younger adults do, as suggested by the socioemotional selectivity theory (e.g., Nashiro et al., 2012), the age-related decline in the effects of uncertainty would be particularly strong when they expect negative outcomes than neutral outcomes.

Methods

Participants

Forty-eight Japanese undergraduate students and 48 Japanese older adults participated in the experiment (see Table 1 for participants' characteristics); they were paid 1,000 JPY/hour for their time. The sample size was determined to ensure a statistical power of 80% to detect the medium-sized interaction (Cohen's $f = .15$) between age, outcome valence and outcome uncertainty.

Procedures

The procedures were identical to those in Study 1, apart from the fact that participants did not complete the PANAS and STAI because of time constraints; instead, they

completed the Japanese Adult Reading Test (JART) at the end of the study, which was used to assess participants' verbal IQ.

Results

Valence Ratings

A 2 (valence) \times 2 (age: young vs. old) ANOVA of the valence ratings of animal names revealed the main effect of valence, $F(1, 94) = 1267.36, p < .001, \eta^2_G = 0.82$, reflecting that the animals used in the negative condition ($M = 2.14; SD = 0.84$) were rated more negatively than those in the neutral condition ($M = 6.36; SD = 1.29$). Although the main effects of age were not significant ($p = .05$), there was a significant interaction between valence and age, $F(1, 94) = 40.81, p < .001, \eta^2_G = 0.12$. Simple effect tests showed that compared to younger adults, older adults rated negative images more negatively ($M_{\text{young}} = 2.35, SD = 0.85; M_{\text{old}} = 1.93, SD = 0.79$), $t(94) = 2.51, d = 0.51, p = .01$, and neutral images more positively ($M_{\text{young}} = 5.81, SD = 1.29; M_{\text{old}} = 6.90, SD = 1.05$), $t(94) = 4.55, d = 0.93, p < .001$. However, the difference between the negative and neutral conditions was significant even for younger adults, $t(94) = 20.66, d = 3.17, p < .001$. These results suggest that across age groups, animals used in the negative condition were considered to be more negative than those used in the neutral condition.

Effects of Uncertainty and Valence on Choice

A 2 (valence) \times 2 (uncertainty) \times 2 (age) ANOVA was performed on the probability of viewing the outcome images to address the study's main aim. This ANOVA revealed a significant main effect of age (Figure 3A), $F(1, 94) = 7.44, p = .008, \eta^2_G = .04$, indicating that older adults viewed images more often than younger adults did ($M_{\text{old}} = .66; SD = 0.39; M_{\text{young}} = .53; SD = 0.40$). The main effect of valence was also significant, $F(1, 94) =$

208.49, $p < .001$, $\eta_G^2 = .41$, such that participants chose to view images in the neutral condition more than in the negative condition as in Study 1 ($M_{\text{neg}} = .34$, $SD = 0.36$; $M_{\text{neu}} = .85$, $SD = 0.25$). Although the main effect of uncertainty was not significant ($p = .46$), we found a significant interaction between valence and uncertainty, $F(1, 94) = 13.35$, $p < .001$, $\eta_G^2 = .01$, and a significant interaction across valence, uncertainty, and age, $F(1, 94) = 6.89$, $p = .01$, $\eta_G^2 = .005$.

To identify the three-way interaction pattern, we subsequently performed 2 (uncertainty) \times 2 (age) ANOVAs separately for each level of valence. In the negative condition, there were significant main effects of uncertainty, $F(1, 94) = 9.16$, $p = .003$, $\eta_G^2 = .011$, which was qualified by a significant interaction, $F(1, 94) = 5.83$, $p = .02$, $\eta_G^2 = .007$. Follow-up simple effect analyses revealed that older adults viewed negative outcome images more frequently than younger adults did in the uncertain condition ($M_{\text{old}} = .47$, $SD = 0.38$; $M_{\text{young}} = .29$, $SD = 0.37$, $\text{CI}_{\text{diff}} = [.03, .33]$), $t(94) = 2.35$, $d = .48$, $p = .04$, whereas the age difference was not significant in the certain condition ($p = .37$; $M_{\text{old}} = .34$, $SD = 0.35$; $M_{\text{young}} = .28$, $SD = 0.32$, $\text{CI}_{\text{diff}} = [-.07, .20]$; Figure 3A). However, in the neutral condition, neither the main effects of uncertainty ($p = .06$) nor the interaction ($p = .27$) were significant (certain: $M_{\text{old}} = .95$, $SD = 0.12$; $M_{\text{young}} = .79$, $SD = 0.27$; uncertain: $M_{\text{old}} = .87$, $SD = 0.24$; $M_{\text{young}} = .77$, $SD = 0.32$). It should be noted that, unlike in Study 1, our uncertainty manipulation did not significantly affect younger adults' decisions to view negative images ($p = .66$, $\text{CI}_{\text{diff}} = [-.05, .08]$). In contrast, older adults viewed negative outcome images more frequently in the uncertain condition than in the certain condition (Figure 3B), $t(94) = 3.85$, $d = .36$, $p = .0004$, $\text{CI}_{\text{diff}} = [.06, .21]$. These results suggest that, contrary to the two hypotheses, older adults,

relative to younger adults, were more likely to view negative outcomes under high uncertainty than low uncertainty.

Self-Report Questionnaires

All p -values reported in this section were based on FDR correction. Older adults showed better scores in the vocabulary test (JART) than younger adults did, $t(94) = -4.28$, $d = 0.88$, $p < .001$, $CI_{diff} = [-10.73, -3.93]$, which is consistent with past findings that vocabulary tends to develop throughout one's lifespan (Verhaeghen, 2003). More interestingly, older adults also showed lower scores relative to younger adults in all four BSSS subscales of sensation seeking (Table 1): experience seeking, $t(94) = 4.45$, $d = 0.91$, $p < .001$, $CI_{diff} = [0.43, 1.11]$, thrill and adventure seeking, $t(94) = 8.19$, $d = 1.68$, $p < .001$, $CI_{diff} = [1.18, 1.93]$, disinhibition, $t(94) = 4.49$, $d = 0.92$, $p < .001$, $CI_{diff} = [0.49, 1.26]$, and boredom susceptibility, $t(94) = 3.99$, $d = 0.81$, $p < .001$, $CI_{diff} = [0.35, 1.04]$. Older adults also showed a lower score in one aspect of curiosity (CEI-II embracing; which concerns one's willingness to embrace the novel, uncertain, and unpredictable events in everyday life), $t(94) = 3.76$, $d = 0.78$, $p < .001$, $CI_{diff} = [0.33, 1.06]$. Although the other subscales of curiosity did not show significant age effects ($ps > .20$; Table 1), these results were consistent with previous findings that older adults tended to report lower scores in self-reported measures of curiosity and sensation seeking (Eachus, 2004; Robinson et al., 2016). We also computed partial correlation between the scores of these self-report questionnaires and participants' choice for negative outcomes under uncertainty after controlling for age, but none of these were significant ($ps > .05$).

Discussion

Study 2 aimed to build on Study 1 by examining the effects of uncertainty on the exploration of negative information across younger and older adults. The existing research provides two predictions regarding the influence of age on the effects of uncertainty: a) age-related general decline in the effects of uncertainty (i.e., older adults would show reduced effects of uncertainty irrespective of the expected outcomes' valence); or b) age-related decline in the effects of uncertainty for negative information (i.e., older adults would show reduced effects of uncertainty especially when expecting aversive outcomes). The results of Study 2 were consistent with neither. Specifically, older adults, relative to younger adults, were more likely to expose themselves to negative outcomes under uncertainty. In contrast to this age-related enhancement in the effects of uncertainty on the exploration of negative information, the same older adults showed reduced levels of information seeking and curiosity in the self-report questionnaires. Moreover, these self-reported measures were not significantly correlated with participants' choices during the choice task. Thus, aging appeared to have different effects on a) self-reported measures of personality traits relevant to information seeking vs. b) behavioral measures of the effects of uncertainty on negative information exploration. It should be noted that while the three-way interaction was significant in the choice task, we also found significant age-related differences in the valence ratings of animals used in this study. Thus, it is possible that the significant interaction across age, valence, and uncertainty in their choice observed in the ANOVA is due to the differential valence evaluations of animals used in the negative vs. neutral condition across different age groups. The results obtained from younger adults were also inconsistent across Studies 1 and 2; our uncertainty manipulation had significant effects on younger adults' choices to view negative outcomes in Study 1, but not in Study 2. Therefore, we investigated

the interaction across the level of valence, age, and uncertainty in one's choice to explore information further in Studies 3 and 4.

Study 3

In Study 3, we examined whether the uncertainty effects on the exploration of negative information were observed even when the alternative was positive (or less negative). Specifically, participants were always given two options and asked to select the image that they wanted to view, as done in other studies involving children and younger adults (Grisanzio et al., 2021; Oosterwijk, 2017; Oosterwijk et al., 2020). For some trials, they were given a negative–positive pair of options, whereas for others, they were given a negative–neutral pair of options. To ensure that the frequency of positive, negative and neutral options was equal, we added a condition where participants were given an additional pair of option of neutral-positive. As in Studies 1 and 2, in half of the trials, participants were unsure about the animals that they would subsequently view (the uncertain condition), whereas in the other trials, they were aware of the animals that they would subsequently view (the certain condition). Thus, Study 3 allowed us to test whether uncertainty drove exploratory behavior for negative outcomes, despite a positive or neutral alternative.

Methods

Participants and Design

As in Study 2, 48 Japanese undergraduate students and 48 Japanese older adults participated in the experiment (see Table 2 for their demographic characteristics). The experiment had a 2 (uncertainty) \times 3 (pair type: negative–neutral, negative–positive vs. neutral–positive) \times 2 (age) design.

Materials

Sixty animals (20 negative, 20 neutral, 20 positive; see Appendix 2) were used. Like in Studies 1 and 2, images of animals were obtained from existing image sets (Kurdi et al., 2016; Lang et al., 2008), as well as from the Internet. Prior to the main study, seven older and five younger adults who did not participate in any other studies reported in this manuscript rated these animals. Stimuli were chosen based on the ratings obtained from these pilot participants (see Supplemental Materials for details).

Procedures

Participants first completed a similar set of questionnaires to those in Study 1 (Table 2); they also completed the UCLA Loneliness Scale (UCLALS) (Russell, Peplau, & Ferguson, 1978) for other purposes not relevant to the present study. They then completed the main choice task (Figure 4A). In each trial, participants saw two covered images with cues. In the certain condition, the covered images were accompanied by the name of the animal behind it as a cue (e.g., “Crab”). In the uncertain condition, the covered images were accompanied with a question mark as a cue. In the positive–neutral condition, one of the cues was positive, whereas the other was neutral; in the negative–neutral condition, one was negative, and the other was neutral; in the negative–positive condition, one was negative, and the other was positive. The animals’ valence was indicated through different colors and schematic faces. Cues in the negative condition were shown in red with a sad face; those in the neutral condition were shown in green with a neutral face; and those in the positive condition were shown in blue with a happy face (Figure 4B).

Participants were asked to press the “k” key when they wanted to view the image of the animal shown on the right side of the screen and the “d” key when they wanted to view the image of the animal shown on the left side of the screen. The cue was replaced by a

corresponding image that was shown for 3 s. There were 60 trials in total (10 trials for each condition). The order of these trials was randomized for each participant.

After the task, participants completed the PANAS again, followed by a valence rating task, where they rated each animal's name in terms of its valence (1: extremely negative – 9: extremely positive). Finally, participants completed the Mini-Mental State Examination (MMSE).

Results

As in Study 1, results from the analyses on PANAS are reported in Supplementary Materials.

Valence Ratings

A 3 (valence: positive, negative, or neutral) \times 2 (age) ANOVA of the valence ratings of animal names revealed a significant main effect of valence, $F(1.30, 122.04) = 538.53, p < .001, \eta^2 = .79$. Animals used in the negative condition ($M = 2.23; SD = 1.21$) were rated more negatively than those in the neutral condition ($M = 5.29; SD = 0.82$), $t(94) = 22.90, p < .001, d = 1.76$ (Tukey), and animals used in the positive condition ($M = 7.15; SD = 1.15$) were rated more positively than those in the neutral condition, $t(94) = 17.34, p < .001, d = 1.05$ (Tukey). Neither the main effect of age nor the interaction was significant ($p = .23, p = .08$).¹

Effects of Uncertainty and Valence on Choice

For each trial with a pair of images, we gave a score of 1 for the valence of an image the participants chose to see, and a score of 0 for the valence of an image the participants chose not to see. For example, when participants chose to see a negative image in a negative-neutral pair, we scored it 1 for negative valence and 0 for neutral valence (and the data for positive valence was considered to be unavailable). These scores were then averaged

for each valence for each participant to represent the probability of seeing an image from each valence, irrespective of the valence of the paired images. Note that the measures were ipsative (i.e., the sum of the probability of seeing negative, neutral and positive images added to 1, because this was a forced-choice measurement); however, previous studies have demonstrated that ANOVA is robust for this type of data (Greer & Dunlap, 1997). A 3 (valence) \times 2 (uncertainty) \times 2 (age) ANOVA was then performed on this choice measure (Figure 5A). This ANOVA revealed a significant main effect of valence, $F(1.34, 125.93) = 97.21, p < .001, \eta^2_G = .47$, reflecting that participants saw positive images ($M = .75, SD = 0.25$) more frequently than neutral images ($M = .52, SD = 0.15$), $t(94) = 8.90, p < .001, d = 1.14$ (Tukey) and neutral images more frequently than negative images ($M = .23, SD = 0.28$), $t(94) = 8.40, p < .001, d = 1.30$ (Tukey). These results were consistent with those from Studies 1 and 2, and suggested that individuals generally preferred information that was relatively more positive (or less negative). Additionally, there was a significant interaction between valence and uncertainty, $F(1.98, 186.19) = 5.43, p = .005, \eta^2_G = .008$. There were no significant interactions including age ($ps > .20$).

Simple effect analyses revealed significant effects of uncertainty in the negative condition, $t(94) = 3.38, d = 0.34, p = .003, \text{CI}_{\text{diff}} = [0.02, 0.09]$, indicating that participants viewed negative images more in the uncertain condition ($M_{\text{old}} = .24, SD = 0.30; M_{\text{young}} = .28, SD = 0.30$) than in the certain condition ($M_{\text{old}} = .17, SD = 0.25; M_{\text{young}} = .22, SD = 0.25$). In contrast, there were no significant effects of uncertainty for either neutral or positive images ($ps > .15$); participants viewed neutral and positive images similarly across the certain (neutral: $M_{\text{old}} = .53, SD = 0.08; M_{\text{young}} = .53, SD = 0.15$; positive: $M_{\text{old}} = .80, SD = 0.24; M_{\text{young}} = .75, SD = 0.23$) and uncertain conditions (neutral: $M_{\text{old}} = .53, SD = 0.12; M_{\text{young}}$

$= .48, SD = 0.21$; positive: $M_{old} = .73, SD = 0.27$; $M_{young} = .74, SD = 0.25$). Thus, our uncertainty manipulation had a clear effect on choice only for negative options, even when participants were given a less negative alternative (Figure 5B).

To examine whether the effects of uncertainty on the choice of viewing negative images were different depending on whether negative images were paired with positive or neutral images, we next focused on trials where participants viewed negative images and ran a 2 (uncertainty) \times 2 (pair type: positive–negative, neutral–negative) \times 2 (age) ANOVA of the probability of seeing negative images (Figures S2A–S2B). Trials without negative images were not included in this analysis. This ANOVA revealed significant main effects of pair type, $F(1, 94) = 10.70, p = .001, \eta^2_G = .006$, and of uncertainty, $F(1, 94) = 11.45, p = .001, \eta^2_G = .011$. However, an interaction between them was not significant ($p = .51$), indicating that participants chose to see negative images more when the outcome was uncertain than when the outcome was certain, irrespective of whether the alternative was neutral ($M_{certain} = .22, SD = 0.27$; $M_{uncertain} = .28, SD = 0.33$) or positive ($M_{certain} = .17, SD = 0.27$; $M_{uncertain} = .24, SD = 0.29$). Neither the main effect of age ($p = .40$), nor any interactions including age were significant ($ps > .05$). These results further confirmed that uncertainty increased participants' decisions to view negative images, even when the alternative was positive, irrespective of age.

Self-Report Questionnaires

All p -values reported in this section were based on FDR correction. Relative to younger adults, older adults showed lower scores in three subscales of BSSS (Table 2): experience seeking, $t(94) = 3.47, d = 0.70, p < .001, \text{CI}_{\text{diff}} = [0.27, 0.98]$, thrill and adventure seeking, $t(94) = 7.26, d = 1.49, p < .001, \text{CI}_{\text{diff}} = [1.13, 1.98]$, and disinhibition, $t(94) = 4.09,$

$d = 0.84, p < .001, \text{CI}_{\text{diff}} = [0.39, 1.11]$. Older adults also showed lower scores in the CEI-II stretching subscale (i.e., a motivation to seek out knowledge and new experiences), $t(94) = 2.48, d = 0.50, p = .02, \text{CI}_{\text{diff}} = [0.09, 0.78]$, and JECS specific curiosity scores, $t(94) = 3.03, d = 0.62, p = .003, \text{CI}_{\text{diff}} = [0.16, 0.77]$. Thus, although the results were slightly different from those of Study 2, they were largely consistent with the notion that older adults showed lower self-reported scores for curiosity and sensation-seeking measures. None of these self-reported measures of curiosity/information seeking were significantly correlated with participants' choice to view negative images under uncertainty after controlling for age ($ps > .15$). Older adults also showed lower MMSE scores than younger adults did, $t(94) = 7.02, d = 1.44, p < .001, \text{CI}_{\text{diff}} = [2.00, 3.58]$.

Discussion

In Study 3, we expanded on Study 2 by including the alternative in each trial. We found that for both older and younger adults, uncertainty increased their preference for viewing negative outcomes, despite an alternative neutral or positive option. Although they generally preferred positive images, the uncertain condition weakened this preference. It should be noted that we found slightly different patterns of results across Studies 1 and 2, such that younger adults' choices to see negative images were enhanced by our uncertainty manipulation in Study 1, but not in Study 2. The results from Study 3 are more consistent with those from Study 1, suggesting that uncertainty likely enhances one's choice to explore negative outcomes, even in younger adults.

Notably, although older adults showed comparable effects of uncertainty relative to younger adults in our choice task, the same older adults demonstrated lower scores in some of the self-report questionnaires on curiosity and information seeking compared to younger

adults. These results, in line with those of Study 2, suggest that the effects of age on self-report questionnaires assessing curiosity and information-seeking traits, do not necessarily match its effects on actual information-seeking behavior under certainty.

Study 4

In Study 4, we aimed to test whether the results from Study 3 were replicated for participants recruited from western countries. We were also interested in the pattern shown by middle-aged adults. Therefore, we recruited participants aged older than 18 and analyzed the effects of age as a continuous variable.

Methods

Participants

A total of 180 participants (men = 102, women = 78, other = 1; $M_{age} = 46.73$, $SD = 17.36$, age range = 18-78) were recruited through the Prolific (<https://app.prolific.co/>).

Materials

Sixty animals (20 negative, 20 neutral, 20 positive; see Appendix 3) were used. Once again, images of animals were obtained from existing image sets (Kurdi et al., 2016; Lang et al., 2008) as well as from the Internet. Prior to Study 4, 15 participants recruited from Prolific (those who did not participate in Study 4) rated the names and photographs (one for each) of 128 animals; the 60 stimuli were chosen based on this pilot study's ratings (see Supplemental Materials for details).

Procedures

The procedures were similar to those used in Study 3, with a few exceptions. First, Study 4 was an online experiment done in English (Studies 1-3 were in-person experiments done in Japanese). Second, because of time constraints, we shortened the choice task; each

animal's name was presented once, and the number of trials was reduced to 30. Third, we included only the demographic questionnaire, BSSS, and CEI-II. Finally, we also excluded the valence rating task and MMSE because of time constraints and practical feasibility.

Results

Uncertainty and Valence's Effects on Choice

As in Study 3, for each level of valence, the probability of viewing the outcome images was obtained after collapsing the valence of paired images (Figure 6A). Consistent with Study 3's results, we found a significant effect of valence, $F(2, 356) = 123.01, p < .001$, $\eta_G^2 = 0.67$, reflecting that participants preferred positive images ($M = .69, SD = 0.27$) over neutral images ($M = .55, SD = 0.16$), $t(178) = 6.48, p < .001, d = 0.63$ (Tukey) and neutral images over negative images ($M = .26, SD = 0.28$), $t(178) = 12.43, p < .001, d = 1.27$ (Tukey). Additionally, there was a significant interaction between valence and uncertainty, $F(2, 356) = 5.94, p = .003, \eta_G^2 = 0.003$. There were no significant interactions including age ($ps > .50$). Follow-up analyses revealed significant effects of uncertainty in the negative condition (Figure 6B; $M_{certain} = .23, SD = 0.24, M_{uncertain} = .29, SD = 0.31$), $t(178) = -3.33, d = 0.25, p = .003, CI_{diff} = [0.02, 0.09]$, but not in the positive ($M_{certain} = .70, SD = 0.25, M_{uncertain} = .68, SD = 0.28$) or neutral conditions ($M_{certain} = .56, SD = 0.13, M_{uncertain} = .54, SD = 0.18; ps = .13$). Thus, the results from Study 3 were replicated in the independent sample.

Next, we examined whether the effects of uncertainty on the choice of a negative image varied depending on the valence of paired images; here, we focused on trials, wherein participants viewed negative images. We found significant effects of uncertainty, $F(1, 178) = 11.11, p = .001, \eta_G^2 = 0.008$, but no other significant effects ($ps > .29$). Thus, the results suggest that across the adult lifespan, individuals' desire to resolve uncertainty is particularly

strong when they expect negative outcomes, even in the presence of positive or neutral alternatives (Figures S3A-S3B).

Self-Report Questionnaires

Relative to younger adults, older adults showed lower scores for BSSS boredom susceptibility, $r(178) = -.46, p < .001$, CI = [-.57, -.34], BSS disinhibition, $r(178) = -.51, p < .001$, CI = [-.61, -.39], and CEI-II embracing, $r(178) = -.24, p < .001$, CI = [-.38, -.10] (all FDR corrected). None of the curiosity and sensation-seeking personality traits were significantly correlated with participants' choice to view negative animals/insects under uncertainty, after controlling for age ($ps > .10$ with FDR).

Discussion

In Study 4, we largely uncovered similar results to Study 3, and found that outcome uncertainty enhanced one's choice to see negative images across younger and older adults; participants in the middle-age group exhibited the same pattern. Taken together, the results support Study 3, suggesting similar effects of uncertainty on the exploration of negative information across the adult lifespan as well as in Asian and Western samples.

General Discussion

Previous research documented that people expose themselves to negative information to resolve uncertainty (Hsee & Ruan, 2016). The first goal of the present study was to address whether one's desire to resolve uncertainty differed depending on outcome valence. We replicated findings from Hsee and Ruan across the four studies—that younger adults exposed themselves to negative information to minimize uncertainty. The present study further revealed that the effects of uncertainty were limited to negative information. Specifically, when outcomes were expected to be neutral or positive, their uncertainty did not

increase participants' choice to view the outcomes. Thus, our findings suggest that uncertainty drives one's desire to explore information, particularly when the information is expected to be negative.

The second goal of the present study was to examine whether both older and younger adults were more eager to explore negative information owing to uncertainty. Consistent with previous research on self-reported measures assessing curiosity and related concepts (for a review see Sakaki et al., 2018), we found that relative to younger adults, older adults had lower sensation-seeking and curiosity scores across Studies 2–4. Nevertheless, we did not find evidence for age-related reductions in the effects of uncertainty on negative information seeking. Instead, we found that both older and younger adults exposed themselves to negative outcomes more in the uncertain condition than in the certain condition. Although a significant three-way interaction was found in Study 2, it was because of a stronger facilitation effect owing to uncertainty in the negative condition for older adults than for younger adults; in other words, older adults were more likely than younger adults to expose themselves to negative outcomes under high uncertainty which was the opposite from our initial expectations. These results suggest that old age brings two rather independent information-seeking effects: even though old age leads to reduced scores in self-reported measures of personality traits relevant to information seeking, it is not necessarily associated with the reduced uncertainty-related effects on negative information exploration.

Effects of Age on Exploratory Behavior

Previous studies based on self-report questionnaires have revealed that as individuals grow older, they show reduced tendencies to explore novel experiences or situations (Giambra et al., 1992; McCrae et al., 1999; Robinson et al., 2016; for a review see

Sakaki et al., 2018). Previous neuroimaging studies have also documented age-related decline in the dopaminergic system in the brain, which is critical for curiosity (Gruber et al., 2014; Oosterwijk et al., 2020). Moreover, previous laboratory studies have identified age-related positivity effects in information processing that can be explained by the socioemotional selectivity theory (Nashiro et al., 2012), as mentioned in the introductory section. Based on these studies, older adults would not explore uncertain information, especially for negative outcomes.

However, this study's findings showed that uncertainty drives exploratory behavior for negative outcomes despite positive alternatives, both for older and younger adults. Thus, the results are inconsistent with the predictions based on prior studies. It is noteworthy that recent laboratory studies on aging and curiosity have demonstrated that when older adults face something potentially interesting, they show similar, or even stronger, levels of curiosity relative to younger adults (Chu & Fung, 2022; Galli et al., 2018; McGillivray et al., 2015). These studies also suggest that older adults benefit from curiosity in learning as observed for younger adults. Our findings are consistent with these results and suggest that although normal aging is associated with lower self-reported scores in measures of personality traits related to curiosity, it does not necessarily impair mechanisms relevant to exploratory behavior under uncertainty.

It is unclear why older adults demonstrate reduced levels of personality traits on curiosity in self-report questionnaires, despite the lack of age-related changes in behavioral measures obtained in experimental settings. One possibility concerns age-related stereotypes. Older adults are typically seen as those who are lonely, and do not have much keeping them busy in their lives (Newman et al., 1997; North & Fiske, 2015). Older adults may internalize

such views about themselves (Levy, 2009), resulting in bias in their responses to self-report questionnaires on curiosity or related concepts, even though their behavior is not very different from younger adults. Another possibility concerns the role of social participation. As individuals get older, social participation often decreases owing to lifestyle transitions (e.g., retirement, fewer childcare burdens etc.; Myroniuk & Anglewicz, 2015). Such lifestyle changes may also affect older adults' responses; for example, when responding to an item "I prefer jobs that are excitingly unpredictable" (an item from CEI-II), older adults may choose a lower rating, simply because they do not necessarily see themselves engaging in jobs on a day to day basis. Thus, their responses to self-report questionnaires may not accurately reflect the degree to which they experience curiosity, and seek new experiences in life. In fact, participants' responses to the self-report questionnaires on trait curiosity or sensation seeking had only weak associations with their desire to view negative animals in the card task in the present study. However, the lack of significant correlations could be due to the lack of statistical power, given that our sample size was not designed to detect such correlations. Future research should address how behavioral measures of curiosity are related to self-report measures on curiosity across the adult lifespan to better understand how the two aspects of curiosity are affected by age.

Findings of this study also appear to contradict the findings of previous neuroscientific research, which has typically shown that the striatum is involved in the motivational saliency of reward and curiosity (Lau et al., 2020). As described in the Introduction section, the striatum is also susceptible to age-related deterioration (Düzel et al., 2010). Thus, these prior studies suggest that older adults experience lower levels of curiosity in general. However, recent research on morbid curiosity has revealed that one's choice to

see negative stimuli out of curiosity is not only associated with striatal activity, but also with activity in the inferior prefrontal cortex (Oosterwijk et al., 2020). The inferior prefrontal cortex is involved in inhibitory control and is susceptible to age-related decline (Eich et al., 2021). Therefore, older adults may not only experience lower motivational saliency due to their impaired striatum function, but also lower inhibitory capacities to downregulate their motivation to see negative images, due to their impaired inhibitory control. These various effects of aging of the brain may result in similar behavioral effects of uncertainty on the exploration of negative information in older and younger adults. Future research should test these possibilities further by integrating behavioral methods, similar to the ones we have used, along with neuroimaging measures.

Unique Effects of Uncertainty for Negative Information

Previous research has yielded mixed views regarding the role of valence in exploratory behavior, even for younger adults. Some researchers have suggested that individuals tend to explore positive information more than negative information (Charpentier et al., 2018; Golman & Loewenstein, 2018; Kobayashi et al., 2019). Other studies have shown that individuals seek information to resolve uncertainty, irrespective of outcome valence (Kobayashi et al., 2019; Kreps & Porteus, 1978; van Lieshout, de Lange, et al., 2021; van Lieshout, Traast, et al., 2021). In contrast, across all four of our studies, we repeatedly observed an uncertainty by valence interaction that outcome uncertainty enhances exploration of negative outcomes but not positive or neutral outcomes. Thus, uncertainty appears to enhance curiosity selectively for initially negative information.

Such selective effects of uncertainty on negative information seeking may have arisen due to boredom. In fact, a recent study suggested that people who felt bored explored

new information even if the information was negative (Bench & Lench, 2019). Given that we conducted numerous trials during our experiments, it seems plausible that participants may have been bored, and the increased boredom during the experiment may have contributed to the enhanced effects of uncertainty, particularly for negative information. To address this possibility, we examined temporal trajectories of participants' choice and addressed whether uncertainty drives the exploration of negative information particularly in the later part of the experiment when participants were expected to be bored. However, the effects of uncertainty did not change from the first half of the experiment to the second half (Tables S1-S4). Thus, it appears that increased boredom during the experiment is not a critical factor influencing the effect uncertainty on negative information seeking.

While the exact mechanisms underlying the selective effects of uncertainty on the exploration of negative information are unknown, a recently proposed theory suggests that both positive valence and certainty determine the utility of information and information-seeking behavior (Golman et al., 2021; Golman & Loewenstein, 2018; see also Redmond et al., 2019). According to the theory, individuals, in general, prefer positive information over negative information (if the level of uncertainty is identical), and certain information over uncertain information (assuming that their valence is equal). Importantly, it has long been known that negative information is particularly aversive, when it is uncertain rather than certain (Arntz et al., 1992). Thus, information which can resolve the uncertainty around negative information could have a higher utility value than information which can solve the uncertainty around neutral or positive information. This interactive effect between valence and uncertainty on the utility of information may have contributed to participants' behavior in

the present study; they chose to expose themselves to negative information under uncertainty, but not to positive and neutral information.

It should be noted that prior to each trial, participants in the present study were given a clear idea about the valence of the animals to be shown (e.g., using different colors or different schematic images of faces). This means that while they were uncertain about which specific animal they would subsequently see, they should have been prepared to see a negative image, even in the uncertain condition. If negative information is experienced aversively, particularly when it is unpredictable as described earlier (Arntz et al., 1992), our manipulation may have contributed to a reduced emotional impact of negative animals. Such attenuated emotional responses may have encouraged participants to expose themselves to negative information in the present study. While this possibility does not explain the selective effects of uncertainty on negative information, future research should examine the interaction between valence and uncertainty in other situations, where valence is also less predictable.

Limitations and Future Questions

Some other important limitations need to be noted. First, the animals were chosen for this study based on the valence and familiarity levels. However, we did not control for other factors, such as arousal, semantic categories, and semantic relatedness. For example, in Study 3, we included several dog breeds in the positive condition (such as dachshund and toy poodle) and more insects in the negative condition (see Appendix 2). However, the animals used in the uncertain and certain conditions were counterbalanced. Therefore, the effects of uncertainty were not necessarily attributable to the effects of any specific animal. Nevertheless, future research needs to examine the effects of these other factors, such as semantic similarity and arousal.

Second, participants' negative information exploration in this study did not necessarily come at an emotional cost. As reported in Supplementary Materials, those who exposed themselves to negative animals more in the uncertain condition were not necessarily in a worse mood after the task (see Supplementary Materials for details). This suggests that the negative information used in the present study was mild in nature. Thus, caution should be exercised when considering the generalizability of the results in terms of negative information with greater emotional and personal implications (e.g., information seeking for health).

Conclusions

The findings presented in this study suggest that uncertainty increases individuals' tendency to deliberately expose themselves to negative information, but not to positive or neutral information. This tendency was seen even in the presence of positive or neutral alternatives. Furthermore, the selective facilitation effects of uncertainty on the exploration of negative information were observed across younger, middle-aged, and older adults, even though older adults reported that they would not be as curious and enjoy sensation as much as younger adults do. These results add to the growing literature, indicating a discrepancy between the effects of age on trait curiosity and those on behavioral effects of curiosity. Additionally, they provide insights into human behavior in the face of uncertainty across the adult lifespan.

Footnote

¹ Given a trend for the interaction, $F(1.30, 122.04) = 2.94, p = .08$, one may wonder if older vs. younger adults perceived animals from three valence conditions differently. However, both older and younger adults rated animals used in the negative condition ($M_{\text{old}} = 1.95$; $SD = 1.05$; $M_{\text{young}} = 2.52$; $SD = 1.30$) more negatively than those in the neutral condition ($M_{\text{old}} = 5.29$; $SD = 0.88$; $M_{\text{young}} = 5.29$; $SD = 0.78$), $ts(94) = 17.71, 14.67, ps < .001$, respectively (Holm), and animals used in the positive condition ($M_{\text{old}} = 7.21$; $SD = 1.00$; $M_{\text{young}} = 7.10$; $SD = 1.29$) were rated more positively than those in the neutral condition, $ts(94) = 12.62, 11.90, ps < .001$, respectively (Holm).

Open Practices Statement

Experimental materials, data, and analysis codes for all experiments are available at the OSF: https://osf.io/d73q4/?view_only=8b39a340c94b45feb012c9b620504a9e

None of the experiments was preregistered.

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Appendix 1: Animals used in Studies 1 and 2

Negative condition: Fly larvae, Mite, Cockroach, Leech, Snake, Hairy caterpillar, Centipede, House centipede, Mosquito, Slug

Neutral condition: Crayfish, Ladybird, Grasshopper, Clione, Jellyfish, Swallowtail butterfly, Scarab beetle, Cicada, Crab, Frog

Appendix 2: Animals used in Study 3

Negative condition: Tarantula, Leech, Slug, Worm, Cockroach, Mite, Mosquito, Termite, Head lice, Hairy caterpillar, Fly, Centipede, Aphid, Flea, House centipede, Mosquito larvae, Hornet, Moth, Green caterpillar, Stink bug

Neutral condition: Shark, Crayfish, Swallowtail butterfly, Ladybug, Water strider, Jellyfish, Pigeon, Vulture, Ostrich, Freshwater clams, Clams, Hippopotamus, Japanese macaque, Black bear, Guinea pig, Alpaca, Rhino, Sea urchin, Frog, Tadpole

Positive condition: Chick, Owl, Penguin, Baby ducks and ducks, Zebra, Dachshund, Toy poodle, White bear, Chihuahua, Whale, Baby seal, Dolphin, Sea otter, Squirrel, Rabbit, Kitten, Shiba Inu dog, Puppy, Panda, Sea turtle

Appendix 3: Animals used in Study 4

Negative condition: Mosquito larvae, Head lice, Cockroach, Mosquito, Maggot, Flea, Rat, Leech, Mite, Snake

Neutral condition: Newt, Mussel, Toad, Jellyfish, Clam, Snail, Lobster, Mantis, Grasshopper, Pigeon

Positive condition: Dolphin, Rabbit, Elephant, Butterfly, Red panda, Pony, Penguin, Puppy, Kitten, Panda

Table 1. Average scores (SD) of demographic and personality characteristics of participants in Studies 1 and 2

	Study 1		Study 2				
	(Young only)	Young		Old			
<i>Demographics</i>							
Age	19.57	(0.88)	19.83	(1.36)	72.06	(4.74)	**
Gender (F/M)	13/22		15/33		21/27		
Years of education	13.04	(1.18)	13.33	(1.56)	14.48	(2.25)	*
<i>PANAS: Positive and Negative Affect Schedule</i>							
Positive (Time 1)	1.99	(0.60)	-	-	-	-	
Negative (Time 1)	1.46	(0.49)	-	-	-	-	
Positive (Time 2)	1.78	(0.64)	-	-	-	-	
Negative (Time 2)	1.63	(0.59)	-	-	-	-	
<i>BSSS: Brief Sensation Seeking</i>							
Experience seeking	3.31	(0.92)	3.36	(0.89)	2.59	(0.80)	**
Thrill and adventure seeking	3.03	(1.14)	3.44	(1.06)	1.89	(0.77)	**
Disinhibition	2.39	(0.97)	2.58	(1.11)	1.71	(0.76)	**
Boredom susceptibility	2.63	(0.99)	2.89	(0.91)	2.19	(0.80)	**
<i>CEI-II: Curiosity and Exploration Inventory</i>							
Stretching	2.82	(0.89)	2.92	(0.93)	2.68	(0.81)	
Embracing	2.69	(0.90)	2.87	(1.02)	2.17	(0.77)	**
<i>JECS: Epistemic Curiosity Scale</i>							
Diverse curiosity	3.43	(0.70)	3.45	(0.89)	3.43	(0.67)	
Specific curiosity	3.44	(0.61)	3.47	(0.72)	3.53	(0.73)	
<i>JART vocabulary test</i>							
correct answer	-	-	26.33	(6.70)	33.67	(9.78)	**

Note: * ($p < .05$), ** ($p < .01$) for group differences in Study 2 (with FDR corrections)

Table 2. Average scores (SDs) of demographic measures and self-report questionnaires for each age group in Study 3.

	Young		Old		
Demographics					
Age	19.19	(1.32)	71.5	(3.31)	**
Gender (F/M)	10/38		26/22		**
Education	12.79	(1.22)	12.44	(2.24)	
<i>PANAS: Positive and Negative Affect Schedule</i>					
Positive affect (Time 1)	1.76	(0.61)	2.13	(0.74)	*
Negative affect (Time 1)	1.42	(0.57)	1.51	(0.59)	
Positive affect (Time 2)	1.86	(0.77)	2.11	(0.85)	
Negative affect (Time 2)	1.56	(0.63)	1.24	(0.41)	*
<i>BSSS: Brief Sensation Seeking Scale</i>					
Experience seeking	3.36	(0.78)	2.74	(0.98)	**
Thrill and adventure seeking	3.36	(1.17)	1.81	(0.90)	**
Disinhibition	2.55	(1.03)	1.80	(0.74)	**
Boredom susceptibility	2.64	(0.88)	2.42	(1.00)	
<i>CEI-II Curiosity and Exploration Inventory</i>					
Stretching	2.76	(0.88)	2.33	(0.83)	*
Embracing	2.41	(0.83)	2.15	(0.73)	
<i>JECS: Epistemic Curiosity Scale</i>					
diverse curiosity	3.22	(0.75)	3.12	(0.75)	
specific curiosity	3.37	(0.79)	2.91	(0.70)	*
MMSE	29.38	(1.08)	26.58	(2.53)	**
JART vocabulary test	26.79	(7.06)	27.08	(10.64)	

*Note: * (p < .05) and ** (p < .01) represents significant group differences (with FDR correction).*

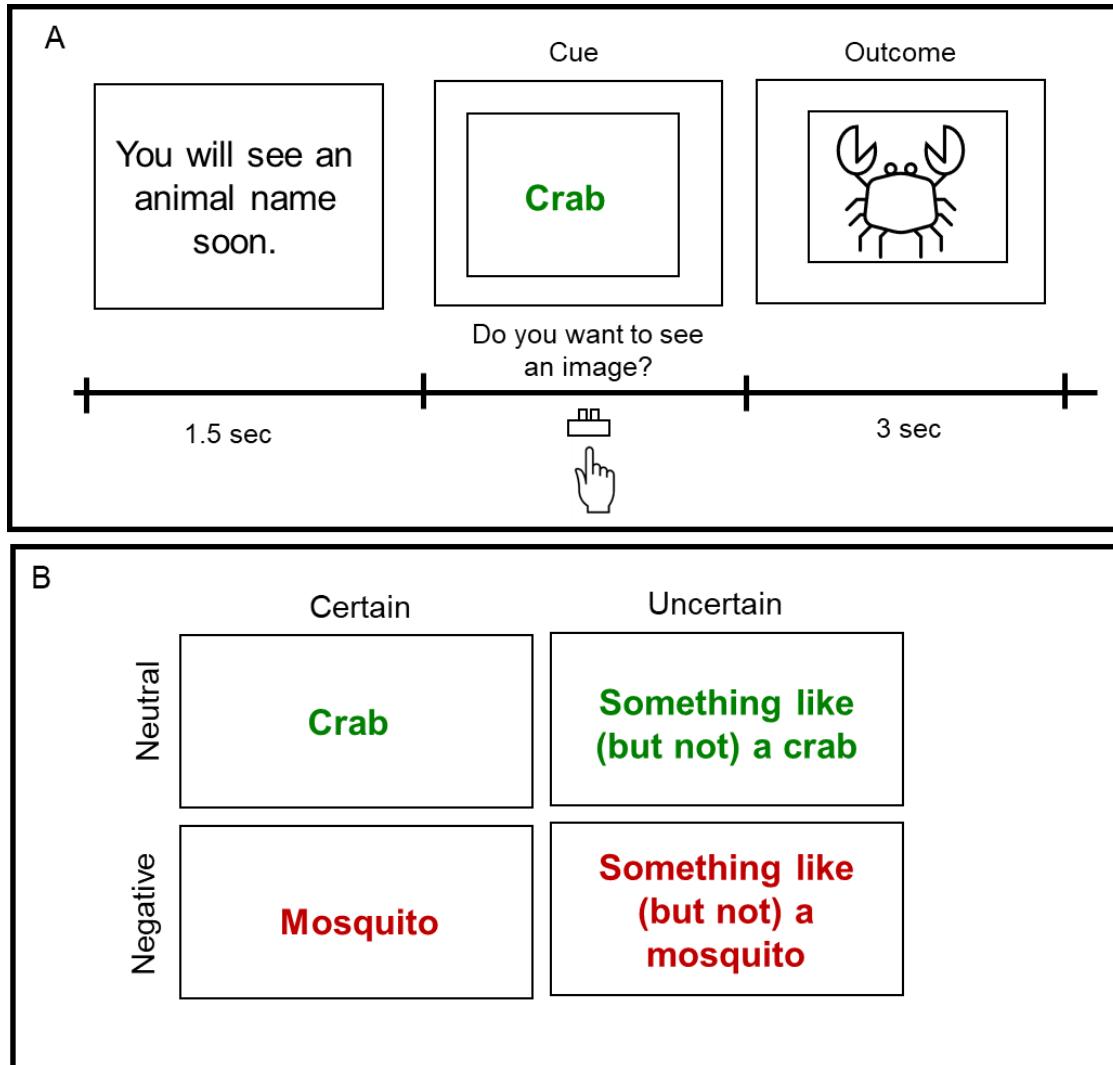


Figure 1. (A) Schematic illustration of each trial; (B) Four possible cue conditions in Studies 1 and 2.

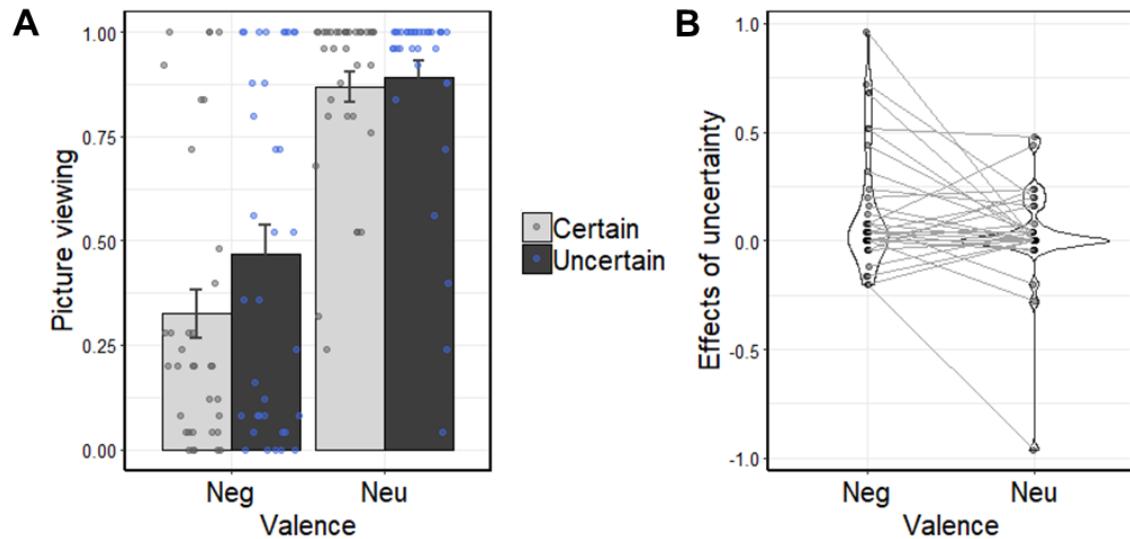


Figure 2. Results from Study 1. (A) The average rate of picture viewing in each condition. Each dot represents the average viewing rate of each participant in each condition. Error bars represent standard errors of means. (B) The difference score between the uncertain vs. certain condition in the average rate of picture viewing (the uncertain condition minus the certain condition). Each pair of connected dots represents one participant.

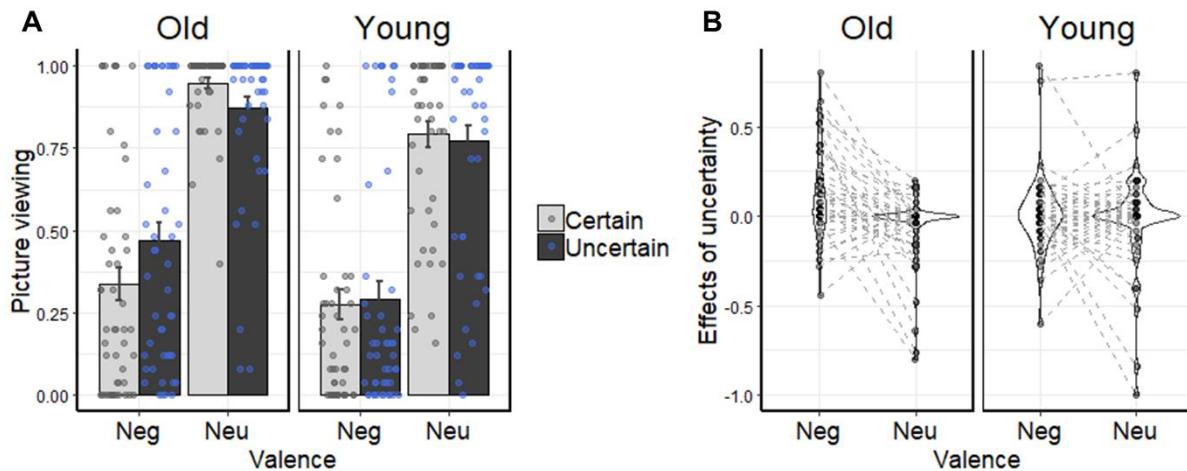


Figure 3. Results from Study 2. (A) The average rate of picture viewing in each condition. Each dot represents the average viewing rate of each participant in each condition. Error bars represent standard errors of means. (B) The difference score between the uncertain vs. certain condition in the average rate of picture viewing (the uncertain condition minus the certain condition). Each pair of connected dots represents one participant.

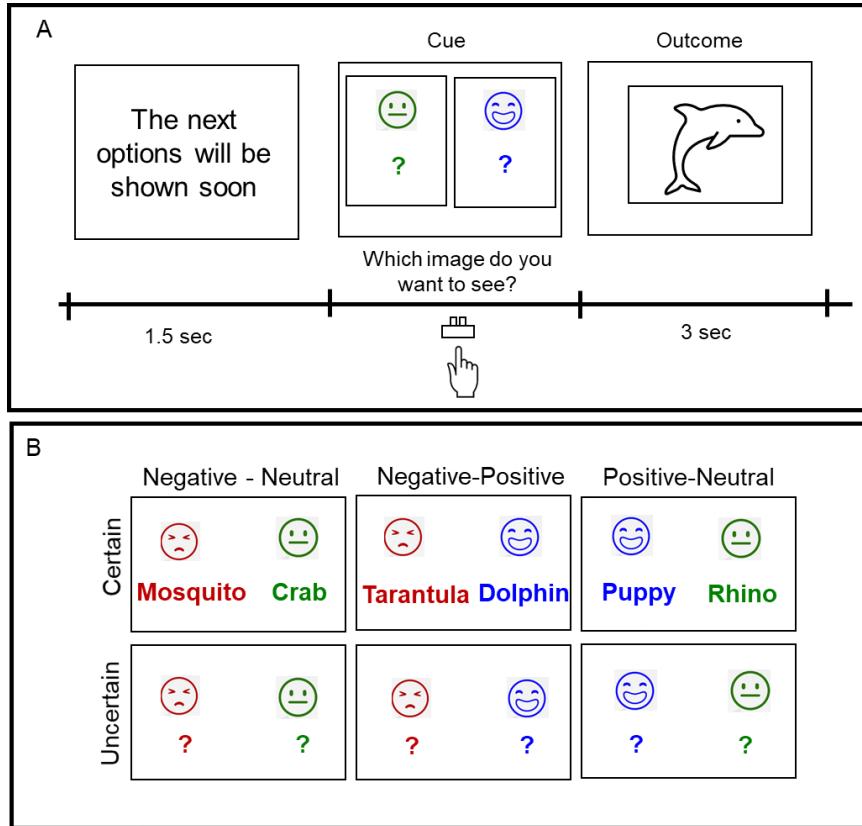


Figure 4. Study 3 procedures. (A) Schematic illustration of a trial in the uncertain condition; (B) possible cues (the locations of the two cues were counterbalanced across trials)

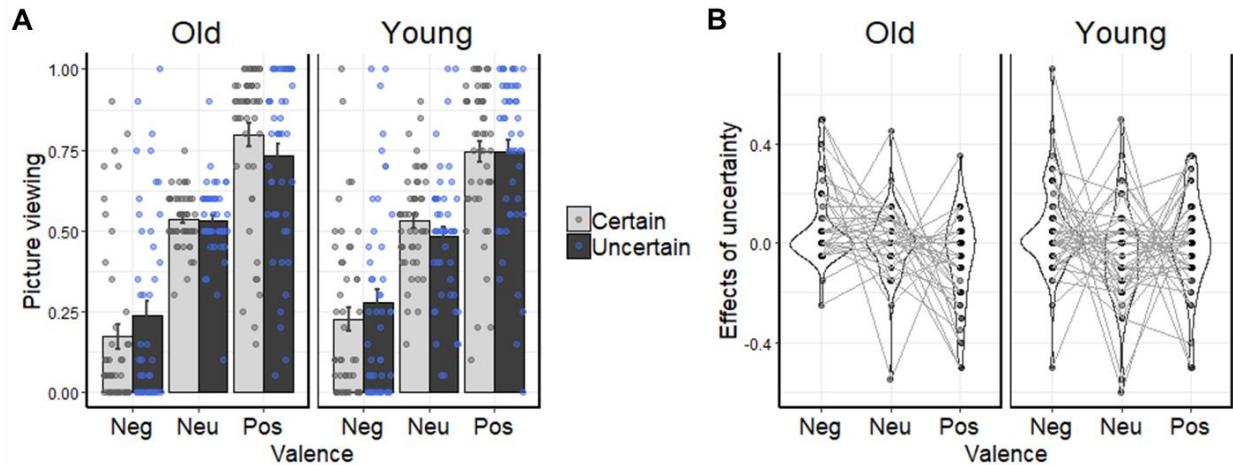


Figure 5. Results from Study 3. The uncertainty manipulation significantly enhanced participants' choice to see negative but not neutral and positive images. (A) The average rate of picture viewing in each condition. Each dot represents the average viewing rate of each participant in each condition. Error bars represent standard errors of means. (B) The difference score between the uncertain vs. certain condition in the average rate of picture viewing (the uncertain condition minus the certain condition). Each pair of connected dots represents one participant.

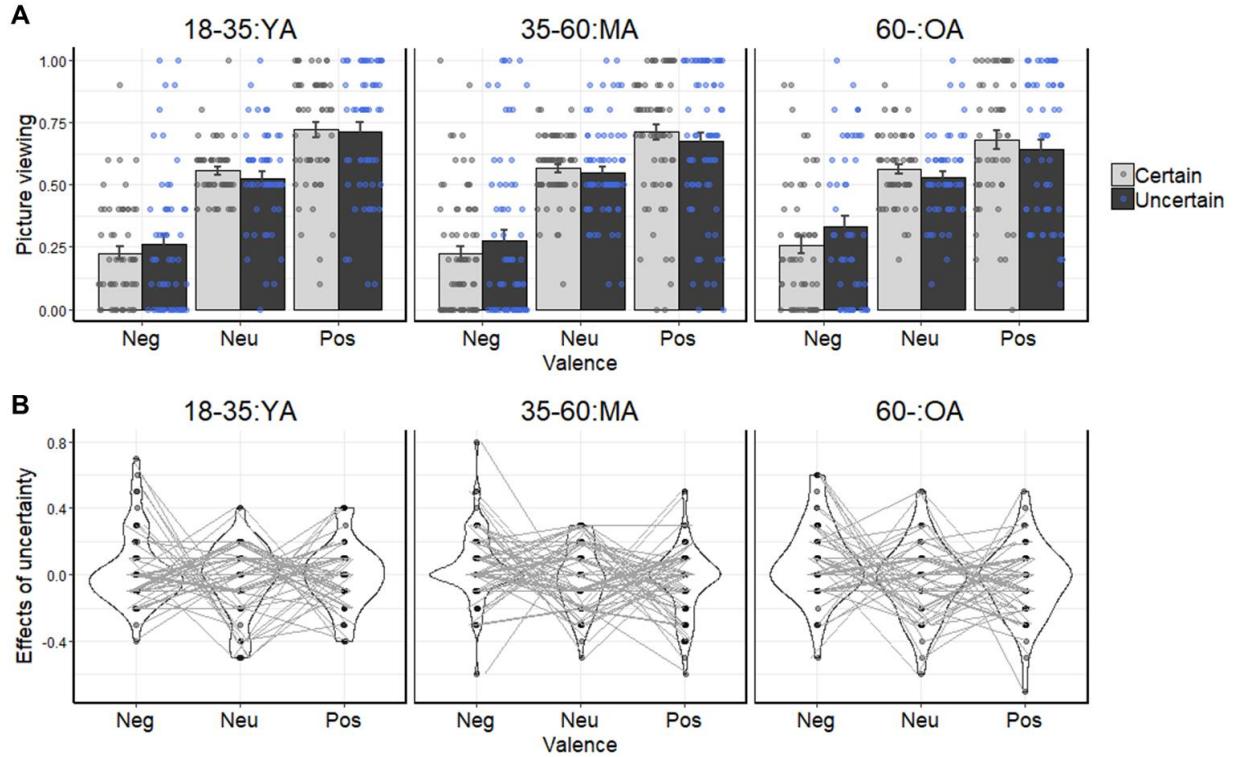


Figure 6. Results from Study 4. (A) The average rate of picture viewing in each condition. Each dot represents the average viewing rate of each participant in each condition. Error bars represent standard errors of means. The uncertainty manipulation significantly enhanced participants' choice to see negative but not neutral and positive images. (B) The difference score between the uncertain vs. certain condition in the average rate of picture viewing (the uncertain condition minus the certain condition). Each pair of connected dots represents one participant.

Supplemental Materials

Materials

Materials in Studies 1 and 2. Prior to Study 1, six older ($M_{\text{age}} = 70.17, SD = 3.25$) and five younger adults ($M_{\text{age}} = 19.60, SD = 1.52$) — who did not take part in any other studies reported in the manuscript — rated the name of 60 animals with regards to their valence (1: extremely negative – 9: extremely positive) and their familiarity (1: “*I do not know it at all*” – 3: “*I know it well*”). They also rated seven photographs of each of the 60 animals with regards to their valence (1: extremely negative – 9: extremely positive). The 20 animals selected for the study had the average familiarity level greater than 2.5. The names of the 10 animals used in the negative condition were rated more negatively than those used in the neutral condition ($M_{\text{neg}} = 1.95, SD = 0.58; M_{\text{neu}} = 5.75, SD = 1.18$). Since the same name was shown for five times during the task (see Choice task), for each animal, five photographs were chosen; those used in the negative condition were rated as more negatively than those used in the neutral condition ($M_{\text{neg}} = 1.87, SD = 0.55; M_{\text{neu}} = 5.61, SD = 0.97$).

Materials in Study 3. Prior to the main study, seven older ($M_{\text{age}} = 71.86, SD = 3.18$) and five younger adults ($M_{\text{age}} = 21.60, SD = 1.14$) — who did not take part in any other studies reported in the manuscript — rated the name of these animals with regards to their familiarity (1: “*I do not know it at all*” – 3: “*I know it well*”) and valence (1: extremely negative – 9: extremely positive). These pilot participants also rated photographs of these animals (i.e., one photo per animal) with regards to their valence (1: extremely negative – 9: extremely positive). All animals had the average familiarity rating greater than 2.5. The 20 animals used in the positive condition (name: $M = 7.22, SD = 0.35$; photo: $M = 7.20, SD = 1.60$) were rated as more positively than those used in the neutral condition (name: $M = 5.29$;

$SD = 0.58$; photo: $M = 5.34$; $SD = 1.77$) that were rated as more positively than those used in the negative condition (name: $M = 1.55$, $SD = 0.25$; photo: $M = 1.59$, $SD = 0.86$). For each animal, we chose one additional image which was similar to the one used in the pilot study and used two images per animal in the choice task.

Materials in Study 4. For each animal name (128 animals in total), 15 adults recruited from the Prolific (male = 4, female = 11; $M_{age} = 40.20$, $SD = 12.20$, 19–58 years old) were asked to indicate if they knew the name or not; and to rate its valence (1: extremely negative – 9: extremely positive) when they knew the name. The participants also rated photographs with regards to their valence (1: extremely negative – 9: extremely positive). Twenty animals used in the positive condition (name: $M = 7.81$; $SD = 0.35$, photo: $M = 7.80$; $SD = 0.49$) were rated as more positively than those used in the neutral condition (name: $M = 5.41$; $SD = 0.40$, photo: $M = 5.51$; $SD = 0.75$) that were rated as more positively than those used in the negative condition (name: $M = 2.84$, $SD = 0.69$, photo: $M = 3.12$, $SD = 0.95$). We also excluded any animals whose names were not known by more than 20% of the pilot participants.

Mood changes

Study 1. Relative to Time 1, participants showed a significantly lower level of positive mood at Time 2 (Table 1), $t(34) = 2.65$, $d = 0.45$, $p = .01$. Negative mood did not significantly change between the two time points ($p = .06$). The degree of changes in their positive or negative mood were not significantly correlated with how often participants viewed negative animals either in the uncertain nor in the certain condition ($ps > .30$).

Study 3. We examined whether participants' choice to see negative animals under uncertainty has any consequences on their mood. Participants' self-reported mood measured

by PANAS did not show a significant change before vs. after the task ($p > .10$). While participants who saw more negative animals in the uncertain condition showed a larger drop in their positive mood after controlling for age (Figure S1), $r(94) = -.21$, $p = .04$, the relation was no longer significant after excluding a potential outlier ($p = .12$). Changes in negative mood were not associated with the choice to see negative images ($p = .39$). Thus, the exposure to negative animals during the uncertain condition was not necessarily associated with worse mood.

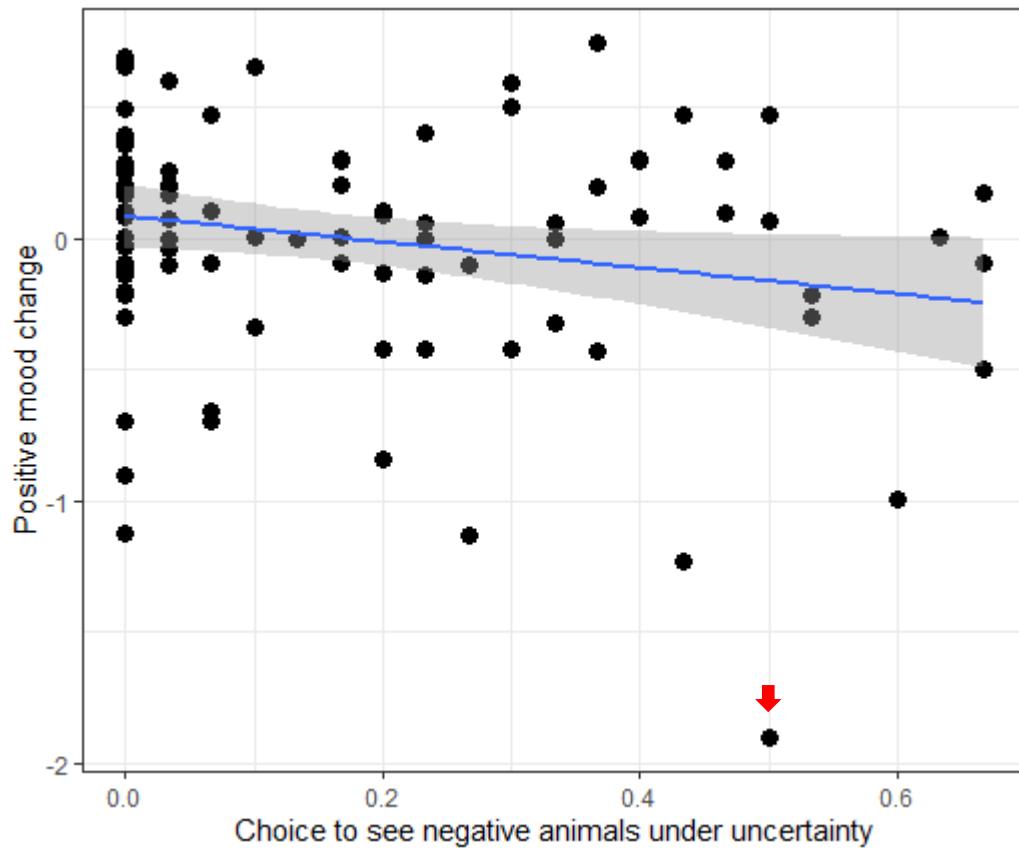


Figure S1. Relationship between the choice to see negative images in the uncertain condition and changes in positive mood. The potential outlier is indicated by a red arrow.

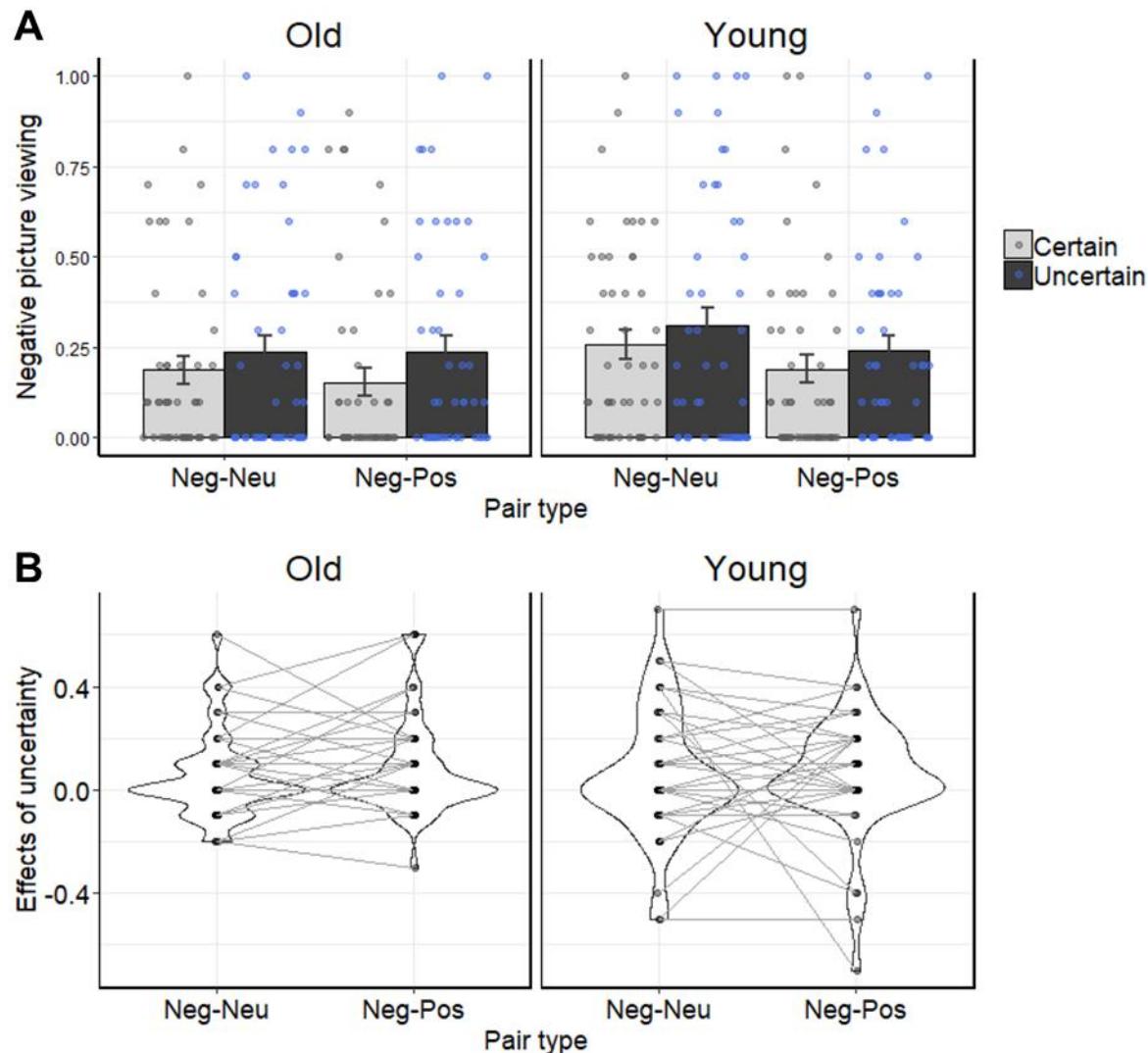


Figure S2. Results from Study 3. The average negative picture viewing rate for each pair type condition. Each dot represents the average viewing rate of each participant in each condition. Error bars represent standard errors of means. (B) The difference between the uncertain vs. certain condition in negative picture viewing (the uncertain condition minus in the certain condition). Each pair of connected dots represents one participant.

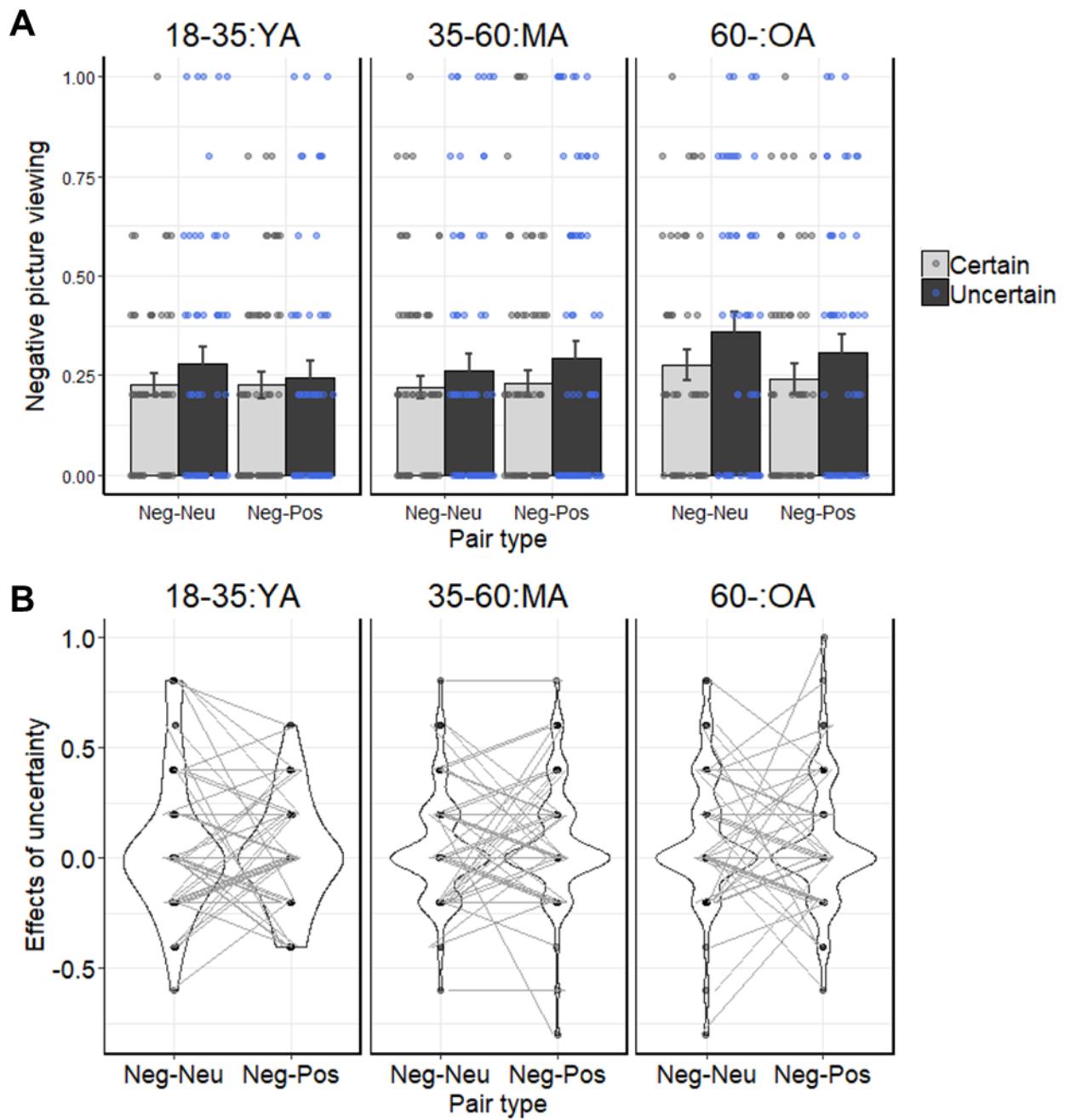


Figure S3. Results from Study 4. The average negative picture viewing rate for each pair type condition. Each dot represents the average viewing rate of each participant in each condition. Error bars represent standard errors of means. (B) The difference between the uncertain vs. certain condition in negative picture viewing (the uncertain condition minus in the certain condition). Each pair of connected dots represents one participant and each line represents a change between the conditions for one participant.

Temporal Trajectories of Participants' Choice Over Time

We examined the temporal pattern of participants' choice by splitting trials into the first half vs. the second half.

Study 1. In Study 1, there was a significant effect of trial order, $F(1,34) = 19.09, p = .001$, reflecting that participants chose to see images more in the first half of the experiment than the latter half of the experiment (Table S1). However, the effects of trial order were not significantly modulated by other conditions.

Study 2. In Study 2, we again found a significant effect of trial order, $F(1,94) = 42.93, p < .001$. This main effect was further qualified by a significant interaction with valence, $F(1,94) = 15.29, p < .001$, and a significant interaction across trial order, valence and age, $F(1,94) = 5.50, p = .02$; reflecting the fact that older adults in general (regardless of the uncertainty condition) chose to see negative images more in the first half than in the latter half (Table S2). However, the effects of trial order were not significantly modulated by our uncertainty manipulation ($ps > .10$).

Study 3. As in Study 2, we also found a significant interaction between order, valence and age, $F(2, 188) = 4.04, p = .02$. But the effects of uncertainty were not significantly modulated by the trial order ($p > .05$; Table S3).

Study 4. There were no significant effects of trial order nor any interactions involving trial order in Study 4 ($ps > .10$), possibly because we had a smaller number of trials in this study than Studies 1-3 (Table S4).

Table S1. The effects of trial order on choices to see images in Study 1

Condition	Early		Late	
	Negative	Neutral	Negative	Neutral
Certain	.37 (0.0605)	.89 (0.0323)	.28 (0.0593)	.85 (0.0400)
Uncertain	.51 (0.0674)	.93 (0.0317)	.42 (0.0760)	.85 (0.0515)

Note: standard errors in parentheses. Trials were split into the first half and the second half.

Table S2. The effects of trial order on choices to see images in Study 2

Group	Early				Late			
	Old		Young		Old		Young	
Condition	Negative	Neutral	Negative	Neutral	Negative	Neutral	Negative	Neutral
Certain	.40 (0.051)	.95 (0.016)	.33 (0.047)	.82 (0.034)	.28 (0.053)	.95 (0.019)	.22 (0.048)	.76 (0.046)
Uncertain	.54 (0.052)	.87 (0.032)	.35 (0.052)	.82 (0.041)	.40 (0.063)	.87 (0.042)	.23 (0.057)	.72 (0.058)

Note: standard errors in parentheses. Trials were split into the first half and the second half.

Table S3. The effects of trial order on choices to see images in Study 3

Group	Old	Young

Condition	Negative	Neutral	Positive	Negative	Neutral	Positive
Early						
Certain	.16 (0.034)	.53 (0.022)	.81 (0.034)	.23 (0.039)	.53 (0.027)	.75 (0.034)
Uncertain	.24 (0.041)	.51 (0.022)	.73 (0.039)	.31 (0.046)	.51 (0.033)	.70 (0.039)
Late						
Certain	.18 (0.043)	.54 (0.021)	.78 (0.042)	.23 (0.039)	.53 (0.028)	.74 (0.038)
Uncertain	.24 (0.049)	.55 (0.027)	.72 (0.046)	.25 (0.044)	.46 (0.036)	.79 (0.038)

Note: standard errors in parentheses. Trials were split into the first half and the second half.

Table S4. The effects of trial order on choices to see images in Study 4

Group	Old			Middle			Young		
Condition	Negative	Neutral	Positive	Negative	Neutral	Positive	Negative	Neutral	Positive
Early									
Certain	.27 (0.038)	.56 (0.023)	.67 (0.040)	.23 (0.030)	.57 (0.023)	.71 (0.034)	.26 (0.034)	.57 (0.026)	.67 (0.036)
Uncertain	.32 (0.044)	.53 (0.029)	.66 (0.037)	.29 (0.042)	.56 (0.027)	.65 (0.037)	.28 (0.041)	.51 (0.031)	.71 (0.036)
Late									
Certain	.25	.56	.69	.22	.56	.71	.18	.54	.77

	(0.042)	(0.028)	(0.041)	(0.032)	(0.020)	(0.035)	(0.029)	(0.024)	(0.036)
Uncertain	.34	.53	.63	.27	.54	.69	.25	.54	.72
	(0.047)	(0.030)	(0.045)	(0.041)	(0.024)	(0.038)	(0.040)	(0.029)	(0.038)

Note: standard errors in parentheses. Trials were split into the first half and the second half.