The interaction of curiosity and reward on long-term memory in younger and older adults

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Abstract

The study was conducted to examine the individual and joint effects of extrinsic motivation, manipulated via monetary reward, and curiosity, a form of intrinsic motivation, on long-term memory in the context of a trivia paradigm, in healthy younger and older adults. During the incidental encoding phase on Day 1, 60 younger and 53 older participants viewed high- and low-curiosity trivia as well as unrelated face stimuli. Half of the participants in each age group received financial rewards for correctly guessing trivia answers. On Day 2, participants completed old-new recognition tests for trivia and face stimuli. Both curiosity and reward were associated with enhanced trivia recall, but the effects were interactive, such that only low-curiosity items benefitted from monetary reward. Neither curiosity nor reward affected face recognition performance in either age group. This pattern was similar for younger and older adults. The current data indicate that individual and joint effects of intrinsic and extrinsic motivation on long-term memory are relatively preserved in healthy aging, a finding that highlights the viability of motivational strategies for memory enhancement into old age. Identifying conditions under which memory for unrelated information benefits from motivational spillover effects is a priority for future research.

Keywords: undermining effect, interest, motivated cognition

The interaction of curiosity and reward on long-term memory in younger and older adults

Why are some facts easily retained while others are forgotten? One contributing factor is epistemic curiosity, the intrinsic motivation to acquire information for its own sake rather than its instrumental utility (Berlyne, 1965; Loewenstein, 1994). Acute states of epistemic curiosity can influence encoding and retrieval. Much like we are likely to remember information learned while anticipating extrinsic rewards (e.g., money; Adcock et al., 2006), we are also more likely to remember information encoded while curious (Kang et al., 2009). Beyond enhancing memory for interesting tidbits, curiosity may affect memory in a more general manner, extending to irrelevant information encountered in close temporal proximity to interesting facts (Gruber et al., 2014). Such effects have been documented in younger adults and in educational settings (Reio, 2004). However, curiosity also benefits memory in older adults (Galli et al., 2018; McGillivray, 2015), potentially offering a motivation-based intervention for mitigating age-related memory decline. An open question, however, is how intrinsic and extrinsic sources of motivation interact to influence older adults' memory processes. Extrinsic reward has been previously shown to undermine the learning benefits of intrinsic motivation in younger adults (Murayama et al., 2010; Murayama & Kuhbandner, 2011). In settings where motivation sources may overlap (e.g., health, education), it is important to understand the interactive effect of intrinsic curiosity and extrinsic reward on older adults' cognitive function.

Several studies have used trivia paradigms to investigate the effect of curiosity on memory for interesting information (Duan et al., 2020; Kang et al., 2009; Marvin & Shohamy, 2016; McGillivray et al., 2015; Murayama & Kuhbandner, 2011) and temporally-contiguous, unrelated information (Galli et al., 2018; Gruber et al., 2014; Stare et al., 2018). In this approach, first established by Kang et al. (2009), participants complete an incidental encoding task (but see

Duan et al., 2020, for an intentional version) in which they encode high- and low-curiosity trivia items. High and low-curiosity designations are established either through a pre-screening for each participant (e.g., Gruber et al., 2014) or based on normed ratings of trivia databases (e.g., Murayama & Kuhbandner, 2011). In some studies, irrelevant stimuli, such as pictures of faces, are presented during the interval between the presentation of the trivia question and the answer, when curiosity is assumed to be at peak. Then, after some delay, a retrieval task tests participants' recall for high- and low-curiosity trivia answers. In studies with irrelevant information included, participants also complete a face recognition task for old faces associated with high- and low-curiosity items. Such studies report significantly higher recall of high-curiosity answers compared to low-curiosity answers in both younger adults (Duan et al., 2020; Kang et al., 2009; Marvin & Shohamy, 2016; Murayama & Kuhbandner, 2011) and older adults (Galli et al., 2018; McGillivray et al., 2015). Moreover, studies have also reported a curiosity-driven benefit for recognition of incidental information (e.g., face stimuli) in younger adults (Gruber et al., 2014; Stare et al., 2018) and in youth (Fandakova & Gruber, 2020), such that faces associated with high-curiosity trivia items are better recognized than those associated with low-curiosity items. One study also demonstrated this effect in older adults in one experiment (Galli et al., 2018; Exp 1), but failed to replicate this finding in a second experiment (Galli et al., 2018; Exp 2). In summary, there is a reliable effect of curiosity on memory of interesting information, but the effect on temporally-contiguous irrelevant information is less well established, particularly in older adults.

The beneficial effect of curiosity on memory has been likened to that of extrinsic reward. For younger and older adults, extrinsic motivation is linked to better memory for items associated with high point value (Castel et al., 2011; Castel et al., 2016), items encoded during

anticipation of financial reward (Spaniol et al., 2014), and items followed by monetary reward feedback (Mather & Schoeke, 2011). The putative mechanism for reward-enhanced memory is dopaminergic modulation of the hippocampus (Adcock et al., 2006; Bowen et al., 2020; Wittmann et al., 2005). Studies investigating the effect of curiosity on memory have implicated many of the same neural substrates as studies investigating the effect of reward on memory, including hippocampus, dopaminergic midbrain and striatal regions (e.g., substantia nigra/ventral tegmental area and nucleus accumbens; Duan et al., 2020; Gruber et al., 2014). This overlap suggests a common neural mechanism underlying intrinsic and extrinsic motivation for supporting memory processes. In other words, receipt of information following a state of curiosity may function similarly to monetary gain following reward anticipation in the brain.

The effects of extrinsic reward on memory for reward-unrelated information diverge from the effects of curiosity. Instead of boosting memory for irrelevant stimuli, reward motivation tends to narrow attention, increasing the selectivity with which target information is remembered (Braver et al., 2014; Chiew & Braver, 2011). This reward-related selectivity effect has been demonstrated in both younger and older adults (for a review, see Swirsky & Spaniol, 2019). For example, both age groups show enhanced selective attention when anticipating monetary gain on a flanker task (Williams et al., 2017), they both bind less incidental details to item memory for high-value items comped to low-value items (Hennessee et al., 2018), and older adults successfully ignore superimposed distractor stimuli at encoding when motivated by virtual points (Swirsky & Spaniol, 2020). One possible mechanism for reward-induced selectivity effects is offered by arousal-biased competition theory (ABC; Mather & Sutherland, 2011). This theory states that noradrenergic arousal, which can accompany reward anticipation/receipt, works to enhance processing of salient or goal-relevant stimuli while dampening processing of

nonsalient or goal-irrelevant information (Lee et al., 2014). In sum, current evidence suggests that intrinsic curiosity and extrinsic reward have similar effects on memory for salient details, but have opposite effects on memory for incidental details.

A final consideration relevant to the current study is the interaction between intrinsic curiosity and extrinsic reward. According to self-determination theory, motivation from extrinsic sources can undermine the benefits of intrinsic motivation on learning (Deci et al., 1999; Ryan & Deci, 2000). For example, younger adults show reduced willingness to voluntarily engage in a task when performance-contingent incentives are offered for performing the task (Murayama et al., 2010). The undermining effect has also been demonstrated in the context of a curiosity-inducing trivia paradigm. In this study with younger adults, half of the participants completed a typical trivia paradigm as described above, while the other half completed the same task but with monetary reward at stake for correctly guessing trivia items during encoding. Results showed that financial reward and curiosity had interactive effects, such that reward enhanced memory for low-curiosity items, but not for high-curiosity items (Murayama & Kuhbandner, 2011). Contrary to these findings, one recent study (Duan et al, 2020) failed to replicate the undermining effect using a similar paradigm with younger adults. Here, memory for trivia showed additive, rather than interactive, effects of financial reward and curiosity. However, there were critical differences between the paradigm used by Duan et al. (2020) and Murayama and Kuhbandner (2011). Specifically, the encoding task was intentional rather than incidental, and reward was contingent on recall performance rather than correct guesses during the encoding task. First, intentional memorizing and incidental learning likely rely on distinct encoding processes. Second, since curiosity operates during encoding, introducing reward motivation at retrieval rather than encoding may reduce the chance of interaction between reward and curiosity. Thus, it

is possible that the undermining effect occurs specifically under implicit learning conditions, and only when intrinsic/extrinsic motivators overlap (both at encoding, rather than one at encoding and one at retrieval).

The undermining effect of reward on curiosity has not yet been documented in older adults. However, compared to younger adults, older adults may be less sensitive to financial incentives during learning (Eppinger et al., 2012) which is consistent with the well-documented age-related decline in dopaminergic and serotonergic transmission (Bäckman et al., 2010; Eppinger et al., 2011). For example, unlike younger adults, older are less enticed by immediate rewards and may show less temporal discounting, which was also associated with lower reward-related striatal activity (Eppinger et al., 2012; but see Seaman et al., 2020, for a meta-analysis that shows no age difference in temporal discounting). Moreover, older adults show reduced incentive-based modulation of attention (Williams et al., 2018). At the same time, it should be noted that older adults' intentional and incidental encoding has been shown to benefit from financial incentives to a similar extent as younger adults (Mather & Schoeke, 2011; Spaniol et al., 2014). Despite some evidence of preserved effects of financial incentives, older adults' weakened sensitivity to financial reward not only suggests that intrinsic motivation may be a preferable route to boosting memory in older adults, but also that older adults may be less susceptible to the undermining effect.

The current study had two main objectives: First, to replicate the curiosity-driven benefit to memory for interesting information and irrelevant, temporally contiguous information in both age groups, and second, to investigate the interaction of intrinsic and extrinsic motivational influences on memory in both age groups. To address these aims, younger and older adults completed a typical trivia paradigm with irrelevant face stimuli included in the encoding task and

memory tested at a ~24-hour delay. Critically, half of each age group were in the extrinsic reward condition. Our hypotheses were as follows. First, we expected to replicate prior reports of curiosity effects on memory for trivia and for unrelated faces in the absence of extrinsic motivation (Gruber et al., 2014). Second, based on prior observations of the undermining effect (Murayama & Kuhbandner, 2011), we expected that the curiosity-driven boost to younger adults' memory would be smaller in the reward condition than in the control condition. By contrast, we expected older adults to show curiosity-driven effects in both conditions, with little or no evidence of undermining by extrinsic reward. An alternative hypothesis was that curiosity and reward would show additive rather than interactive effects (e.g., Duan et al., 2020).

Method

Participants

Participants in the final sample included 60 younger adults (aged 18-35; 40 female) and 53 older adults (aged 60 or older; 33 female). The final total sample size thus approximated the a-priori sample size target (N = 108) determined using a power analysis with G-Power (Faul, Erdfelder, Lang, & Buchner, 2007), requiring a power of at least .95 to detect a medium-sized interactiont ($f \geq .25$) of) of a between-subjects factor and a within-subjects factor in each age group, assuming an alpha error probability of .05 and a correlation among levels of the within-subjects factor of .50 or higher. Younger adults were recruited from the community. Older adults were recruited from the Ryerson Senior Participant Pool, a database of community-dwelling seniors. Eligibility criteria included normal (or corrected-to-normal) vision and absence of neurological, psychiatric, or cardiovascular conditions that might affect cognitive performance. In total, 71 younger adults were tested, but 11 were excluded for analysis due to technical issues during Session 2 (n = 6), failure to return for Session 2 (n = 4), or insufficient low-curiosity

responses during the screening task (n = 1). A total of 74 older adults were tested but 21 were excluded for analysis due to technical issues during Session 2 (n = 2), failure to return for Session 2 (n = 3), insufficient low-curiosity questions from the screening task (n = 11), scoring below 26 on the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005, n = 4), and reporting an awareness of the memory test (n = 1). Participants in each age group were randomly assigned to the control condition or the reward condition. All participants received CAD 36 for participation (CAD 24 after Session 1; CAD 12 after Session 2). Participants in the reward condition received an additional performance-contingent bonus of up to CAD 12.75 after Session 1. All participants provided written informed consent, and study procedures were reviewed and approved by the Ryerson University Research Ethics Board.

Materials

Experimental tasks were programmed in E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA) and presented on a 17-inch computer display. Text was black and set to size 32, Arial font. For the screening task, stimuli included 282 trivia questions drawn from various online trivia databases (see Appendix A for full list of trivia items used). For the encoding task, stimuli included a participant-specific subset of 100 trivia questions from the screening task. Based on each participants' responses during the screening task, the 100 trivia questions used in the encoding task were classified as high-curiosity (n = 40), low-curiosity (n = 40), or known (n = 20). The encoding task also included 100 gray-scale, emotionally neutral faces (50 younger-adult and 50 older-adult faces) taken from the CAL/PAL Face database (Minear and Park, 2004).

For the face recognition task in Session 2, stimuli included 80 faces from the encoding task (40 each from high-curiosity and low-curiosity trials) as well as 40 new faces. Half of the

faces in each of these sets were younger-adult faces and half were older-adult faces. The trivia recall task included a total of 80 trivia questions including 40 high-curiosity questions and 40 low-curiosity questions.

Procedure

Session 1

Session 1 began with the screening task, followed by paper-and-pencil questionnaires, followed by the encoding task. Participants in the reward condition received a bonus that was contingent on performance in the encoding task, whereas those in the control condition did not.

Screening Task. Participants viewed trivia questions presented in random order. Each trivia question was followed by a confidence rating ("How confident are you that you know the answer?") and a curiosity rating ("How curious are you to find out the answer?"). These trials continued until participants had identified 40 unknown high-curiosity questions (confidence rating < 6 and curiosity rating > 3), 40 unknown low-curiosity questions (confidence rating < 6 and curiosity rating < 4) and 20 known questions (confidence rating = 6). See Figure 1a for a schematic of the screening task.

Encoding Task. After the participant had completed unrelated paper-and-pencil questionnaires (approximately 10 minutes), the experimenter administered the encoding task. Throughout the encoding task, participants gave verbal responses and the experimenter entered these responses using the number keys for rating screens or letter keys for trivia guesses which appeared as visible text on the screen for participants to see. This was done to remove demand from typing for older adults. The paradigm combined elements of the encoding tasks employed by Gruber et al. (2014; incidental face stimuli) and by Murayama and Kuhbandner (2011; guessing and rewarding trivia answers). On each trial, a trivia question appeared on the screen,

followed by a face stimulus and a judgment screen ("Do they know the answer?"). Participants were then prompted to guess the answer to the trivia question or pass. The final screen revealed the correct answer. Participants in the reward condition earned $0.25 per correct answer. All answers that were guessed correctly were removed from subsequent analyses. See Figure 1b for a schematic of the encoding task.

Session 2

On the following day (~24 hours post-encoding), participants returned to the laboratory and received a surprise face recognition task and trivia recall task. The order of these tasks was counterbalanced across participants within each age group and condition. There was no difference in the tasks for those in the control condition versus the reward condition.

Face Recognition Task. On each trial, participants saw an old or new face stimulus and indicated using the left and right arrow keys whether they recognized the face from Session 1. Participants then rated their confidence in their recognition decision. See Figure 2a for schematic of the face recognition task.

Trivia Recall Task. On each recall trial, participants saw a high- or low-curiosity trivia question from the encoding task for 6 s, followed by a prompt to recall the answer or pass. Participants answered verbally and the experimenter recorded their responses. See Figure 2b for a schematic of the trivia recall task.

Results

To assess overall performance on the trivia recall task, the proportion of correctly recalled trivia answers was calculated for each participant (see Table 1 and Fig. 3b). Any trivia items that were correctly guessed during the encoding task were removed from the recall analysis. Answers were scored by two independent coders and discrepancies were resolved via

discussion. Interrater reliability was near ceiling (98.3% agreement). Trial-level recall outcomes (0 = not recalled, 1 = recalled) served as the dependent variable in all subsequent mixed model analyses.

To assess overall face recognition accuracy, the corrected recognition rate (hit rate minus false-alarm rate) was calculated for each participant (see Table 1 and Fig. 3a). Trials in which confidence was rated as "1" were removed from the analysis to account for guessing. While accuracy provided information about overall recognition performance, only the responses to old items were informative about differences related to encoding conditions (control versus reward; high versus low curiosity). Therefore, trial recognition outcomes (0 = miss, 1 = hit) were used as the dependent variable in a series of mixed model analyses, described below.

Mixed Model Analyses

To account for the clustered data structure of trials within participants and the dichotomous nature of the dependent variables (trial-level recognition and recall outcomes), logistic mixed effects models were estimated for both dependent variables. All statistical analyses were carried out in R version 1.3.959 (R Core Team, 2020). Mixed models were estimated using the glmr function of the lme4 package (Bates et al., 2015); *p* values for model coefficients were estimated using the lmerTest package (Kuznetsova et al., 2017); and fixed effects and interactions were tested using the Anova function from the car package (Fox & Weisberg, 2019) and are reported as Wald chi-square tests. For ease of interpretation, fixed effects coefficients were exponentiated to calculate odds ratios (Murayama et al., 2014).

For both face recognition and trivia recall, dependent variables were regressed on curiosity rating (quasi-continuous, from 1 to 6), age group (categorical/binary), and condition (categorical/binary) as well as all possible two-way interaction terms and the three-way

interaction term. Random effects models were estimated to account for repeated observations (i.e., trials) within participants. Curiosity ratings were grand mean-centered and dichotomous variables were effects-coded to examine main effects.

Trivia Recall

Results of the logistic mixed model estimation are reported in Tables 2 and 3. To test the main effects of curiosity rating, age group, and condition, the final model included trial-level recall accuracy regressed on trial-level curiosity rating, age group, and condition, as well as their two-way interaction terms. The three-way interaction term was not significant and was dropped to improve model AIC. Results from this model indicated significant main effects of curiosity rating, $\chi^2(1) = 80.38$, $p < 0.001$, and condition, $\chi^2(1) = 5.36$, $p = 0.02$. These effects were qualified by a significant Curiosity x Condition interaction, $\chi^2(1) = 4.74$, $p = 0.03$. The effect of age group (see Figure 3b) and its two-way interactions were not significant, Age: $\chi^2(1) = 2.04$, $p = 0.15$; Age x Condition: $\chi^2(1) = 0.95$, $p = 0.33$; Age x Curiosity: $\chi^2(1) < .01$, $p = 0.98$.

To probe the Curiosity x Condition interaction, two additional models were estimated with the control condition dummy-coded as 0 and the reward condition coded as 1, and vice versa, to isolate the curiosity effect within each condition. Odds ratios from these models indicated that a 1-unit increase in curiosity ratings made correct trial-level recall 1.31 times more likely in the control condition but only 1.18 times more likely in the reward condition. In other words, as curiosity increased, the odds that a trivia item was recalled increased more in the control condition than in the reward condition (Figure 4). See Table 3 for the fixed-effect estimates from the models used to probe the interaction. Consistent with our hypothesis, we replicated the “undermining effect” reported by Murayama and Kuhbandner (2011), but unexpectedly, the effect occurred in both age groups.

Face Recognition

Results of the face recognition logistic mixed model analysis are reported in Table 2. The final model regressed trial-level accuracy (hits vs. misses) on trial-level curiosity rating, age group, and condition, as well as the two-way interaction terms. The three-way interaction term was non-significant and was dropped to reduce model complexity and improve model AIC. Results from this model indicated no significant effects of curiosity rating, $\chi^2(1) = 0.44$, $p = 0.51$, age group, $\chi^2(1) = 1.49$, $p = 0.22$, or condition, $\chi^2(1) = 0.83$, $p = 0.36$. Likewise, none of the interactions was significant; Curiosity x Condition, $\chi^2(1) = 0.42$, $p = 0.52$; Curiosity x Age, $\chi^2(1) = 0.56$, $p = 0.45$; Condition x Age, $\chi^2(1) = 0.17$, $p = 0.68$. In other words, contrary to our hypotheses and prior work, an increase in the curiosity rating during encoding did not increase the odds of subsequent successful face recognition (odds ratio = 1.01).

In summary, the likelihood of recognizing incidentally encoded faces was not modulated by differences in intrinsic and extrinsic motivation at encoding. By contrast, the likelihood of recalling trivia was greater for high-curiosity trivia and for participants in the reward condition. However, the curiosity-driven boost to recall performance was stronger in the control condition than in the reward condition. Again, this pattern was similar in younger and older adults.

Discussion

The current study sought to investigate the effects of intrinsic and extrinsic motivation on memory in younger and older adults. Participants encoded trivia answers that elicited varying levels of curiosity, an intrinsic motivator. Half of the participants were also motivated extrinsically, by the opportunity to earn money for correctly guessing answers to questions. Both sources of motivation improved memory for trivia answers in both age groups. Furthermore, the two sources of motivation interacted, such that participants in the reward condition benefitted

less from curiosity than those in the control condition. However, neither type of motivation affected memory for unrelated faces encountered amidst curiosity-inducing trivia.

Our hypothesis about the effects of curiosity on memory for target and incidental information was partially supported. As predicted, we replicated the canonical curiosity-driven boost to memory for interesting facts in both age groups. By contrast, this effect did not extend to recognition of unrelated faces. Our next hypothesis about the interaction of curiosity and financial reward was also partially supported. The effect of curiosity on trivia recall was stronger in the control condition than in the reward condition. However, contrary to expectation, this interaction was present in both younger and older adults.

It is unclear why we did not replicate the effect of curiosity on incidental face memory (Galli et al., 2018; Gruber et al., 2014; Stare et al., 2018). However, as with any small effect, it is not expected to emerge in every dataset (e.g., Galli et al., 2018, reported the effect in Experiment 1 but not Experiment 2). The current study, and most prior studies, had relatively small sample sizes and are underpowered to detect small effects. In addition, there were important differences between the encoding task used in the current study and typical prior studies that have demonstrated curiosity-driven boosts to incidental face recognition memory. First, our task borrowed aspects of a procedure used by Murayama and Kuhbandner (2011) to test the interaction of curiosity and financial reward on memory. Therefore, the contiguity between the incidental face stimulus and the trivia answer was disrupted by a guessing screen. If incidental face memory depends more on curiosity satisfaction (Marvin & Shohamy, 2016), surprise (Baranes et al., 2015), or post-answer interest (McGillivray et al., 2015) than on the anticipation associated with curiosity, then this disruption may have disrupted the effect. However, recent work suggests that incidental memory enhancement from curiosity is contingent on proximity to

curiosity elicitation rather than curiosity satisfaction (Murphy et al., 2020). If curiosity elicitation is the critical component process, the obstruction should not have influenced curiosity-enhanced memory for incidental faces.

Another notable difference between the current paradigm and prior studies testing the effect of curiosity on incidental face recognition was that the experimenter acted as a scribe. Rather than interfacing with the task directly, participants dictated their responses aloud to the experimenter to enter on their behalf. This may have influenced participants' level of engagement with face stimuli and introduced an element of social desirability when participants had to indicate whether the person shown in the picture was likely to know the answer to the trivia question (e.g., "I don't want to seem judgmental, so I'll say yes").

An alternative perspective on the current findings relates to memory selectivity effects of reward anticipation and arousal. According to ABC theory, noradrenergic arousal, associated with states of reward anticipation (Knutson & Greer, 2008) and curiosity (Sakaki et al., 2018), biases attention and memory processes toward task-relevant stimuli while suppressing task-irrelevant stimuli (Mather & Sutherland, 2011). However, this perspective is not consistent with our results, as it would predict greater memory selectivity associated with high-curiosity than low-curiosity trials.

One interpretation of our results is that financial reward undermines the effects of curiosity on learning (see Murayama & Kuhbandner, 2011). In support of this view, participants' trivia recall in the control condition benefitted more from their level of curiosity than those in the reward condition who were motivated by the prospect of financial reward. An alternative interpretation is that those in the reward condition reached a performance ceiling, such that there was less room for improvement in trivia recall as low-curiosity memory performance was

already relatively high. This interpretation is consistent with Duan et al.'s (2020) finding that intrinsic curiosity and extrinsic reward have additive, rather than interactive, effects on trivia learning.

The different interpretations are not mutually exclusive and future research should aim to disentangle the conditions under which reward undermines or complements curiosity-driven learning. Regardless of the precise nature of the interaction between reward and curiosity, our findings suggest that intrinsic motivation to learn from curiosity leads to an almost identical increase in the probability of correctly recalling a trivia answer as extrinsic motivation from reward. Therefore, interventions aimed at enhancing memory and learning outcomes can target intrinsic motivation states (e.g., curiosity, interest, satisfaction, and surprise; Ozono, et al., 2020; Ryan & Deci, 2000;) instead of extrinsic contingencies of reinforcement (e.g., monetary bonuses, testing grades; Slavin, 2010; Stan, 2012)

Lastly, older adults demonstrated the same pattern of performance as younger adults. While a null effect does not conclusively indicate the absence of an age difference (Lakens et al., 2020), the results also do not support the prediction that older adults' memory would show reduced sensitivity to extrinsic motivation. This is not the first study of motivation-cognition interactions to report a null effects of age for both intrinsic and extrinsic motivation (Galli et al., 2018, Exp 2; Mather & Schoeke, 2011; McGillivray et al., 2015; Spaniol et al., 2014). These findings are particularly interesting in the face of well-documented dopaminergic decline and changes in reward-related brain activation (Bäckman et al., 2010 ; Dreher et al., 2008; Eppinger et al., 2011), age differences in temporal discounting of reward (Eppinger et al, 2012), and changes in motivational priorities across the lifespan (Carstensen et al., 1999), which may increase older adults' preference for non-financial rewards (e.g., social rewards; Rademacher et

al., 2014). The current findings suggest that both intrinsic curiosity and financial reward may remain viable methods for boosting memory in older adults.

The current study had several limitations. First, its sample size, while based on an a priori power analysis and comparable to other studies, was relatively small. While the study was sufficiently powered to detect the two-way interaction-of-interest within each age group, a larger sample size would strengthen our conclusion about the differences—or lack thereof—in this interaction between the age groups. Second, the findings should not be generalized beyond the populations included in this research (predominantly White, urban, highly educated, and healthy younger and older adults). Third, the study used behavioural measures only. In future work, a multi-method approach to studying the impact of extrinsic reward on curiosity-enhanced memory could give insight into the neural substrates of the two types of motivational influences, which are likely overlapping (but see Duan et al., 2020). Similarly, the use of eye-tracking could shed light on the contributions of curiosity-related arousal to subsequent memory performance (Baranes et al. 2015; Kang et al., 2009).

In summary, the current study demonstrates that older adults may retain the ability to prioritize information that they are curious about and that their learning is influenced by concurrent sources of intrinsic and extrinsic motivation, similar to younger adults. The finding that older adults' memory is sensitive to their level of curiosity can be used to inform interventions, in much the same way that curiosity induction is integrated in educational contexts to improve academic outcomes in younger adults. Beyond its downstream effects for cognition, curiosity is also an important motivational factor in physical and mental health across the lifespan (Sakaki et al., 2018) and thus represents a promising target to promote healthy aging.

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Table 1. Descriptives for task performance on face recognition and trivia recall.

		Younger Adults				Older Adults			
		Control		Reward		Control		Reward	
	Overall	Lo Cur	Hi Cur	Lo Cur	Hi Cur	Lo Cur	Hi Cur	Lo Cur	Hi Cur
Face Recognition									
Hit rate	0.56 (0.50)	0.52 (0.50)	0.53 (0.50)	0.55 (0.50)	0.54 (0.50)	0.57 (.50)	0.56 (0.50)	0.61 (0.50)	0.61 (0.50)
False Alarm rate	0.10 (0.10)	—	—	—	—	—	—	—	—
Corrected accuracy	0.46 (0.39)	—	—	—	—	—	—	—	—
Trivia Recall									
Proportion correct	0.60 (0.49)	0.49 (0.50)	0.59 (0.49)	0.62 (0.49)	0.65 (0.48)	0.57 (0.50)	0.66 (0.47)	0.60 (0.49)	0.66 (0.47)

Notes. Means (standard deviations) for memory performance. Lo = low. Hi = high. Cur = curiosity. Low and high curiosity were binned according to prior studies that used a 6-point curiosity rating scale (e.g., Gruber et al., 2014; Galli et al., 2018); low = 1-3, high = 4-6.

Table 2. The estimates of the coefficients of the fixed effects for the final models

	Estimate	SE	z	p	Odds ratio
Trial-level face recognition accuracy					
Intercept	0.29	0.08	3.52	**<.01**	1.34
Curiosity (mean-centered)	0.01	0.01	0.58	0.56	1.01
Age group (effects-coded)	0.10	0.08	1.22	0.22	1.11
Condition (effects-coded)	0.07	0.08	0.94	0.35	1.08
Curiosity * Age Group	-0.01	0.01	-0.75	0.45	0.99
Curiosity * Condition	-0.01	0.01	-0.65	0.52	0.99
Condition * Age Group	0.03	0.08	0.41	0.68	1.03

	Estimate	SE	z	p	Odds ratio
Trial-level trivia recall accuracy					
Intercept	0.50	0.07	7.57	**<.01**	1.65
Curiosity (mean-centered)	0.22	0.03	8.66	**<.01**	1.25
Age group (effects-coded)	0.09	0.07	1.43	0.15	1.10
Condition (effects-coded)	0.15	0.07	2.19	**0.03**	1.16
Curiosity * Age Group	<0.01	0.03	0.02	0.98	1.00
Curiosity * Condition	-0.05	0.02	-2.18	**0.03**	0.95
Age Group * Condition	-0.06	0.07	-0.98	0.33	0.94

*Table 3. The estimates of the coefficients of the fixed effects for the models used to probe the Curiosity * Condition interaction effect on trial-level trivia recall accuracy*

	Estimate	SE	z	p	Odds ratio
Model 1: Condition dummy-coded with control as the reference group					
Intercept	0.36	0.09	3.81	**<.01**	1.43
Curiosity (mean-centered)	0.27	0.03	7.88	**<.01**	1.31
Age group (effects-coded)	0.16	0.09	1.70	0.09	1.17
Condition (dummy-coded)	0.29	0.13	2.19	**0.03**	1.34
Curiosity * Age Group	<0.01	0.03	0.02	0.98	1.00
Curiosity * Condition	-0.11	0.05	-2.18	**0.03**	0.90
Age Group * Condition	-0.13	0.13	-0.98	0.33	0.88
	Estimate	SE	z	p	Odds ratio
Model 2: Condition dummy-coded with reward as the reference group					
Intercept	0.65	0.09	6.90	**<.01**	1.91
Curiosity (mean-centered)	0.17	0.04	4.59	**<.01**	1.18
Age group (effects-coded)	0.03	0.09	0.32	0.75	1.03
Condition (dummy-coded)	-0.29	0.13	-2.19	**0.03**	0.75
Curiosity * Age Group	<0.01	0.03	0.02	0.98	1.00
Curiosity * Condition	0.11	0.05	2.18	**0.03**	1.11
Age Group * Condition	0.13	0.13	0.98	0.33	1.14

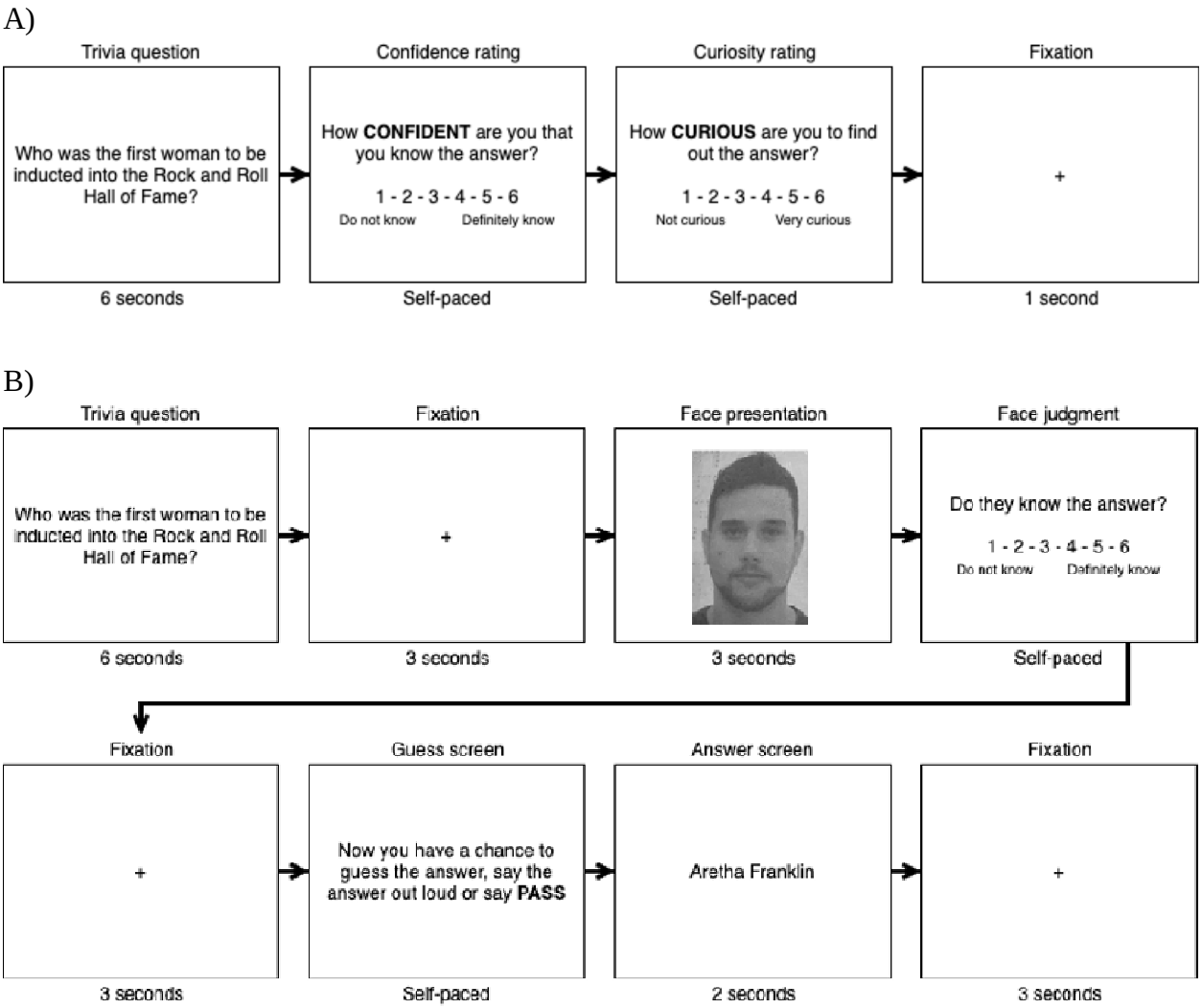

Figure 1. Session 1 tasks. A) Pre-screening task to determine personalized lists of high and low-curiosity trivia items for the encoding task. B) Incidental encoding task in which participants guessed answers to high and low-curiosity trivia items while making judgment about unrelated faces.

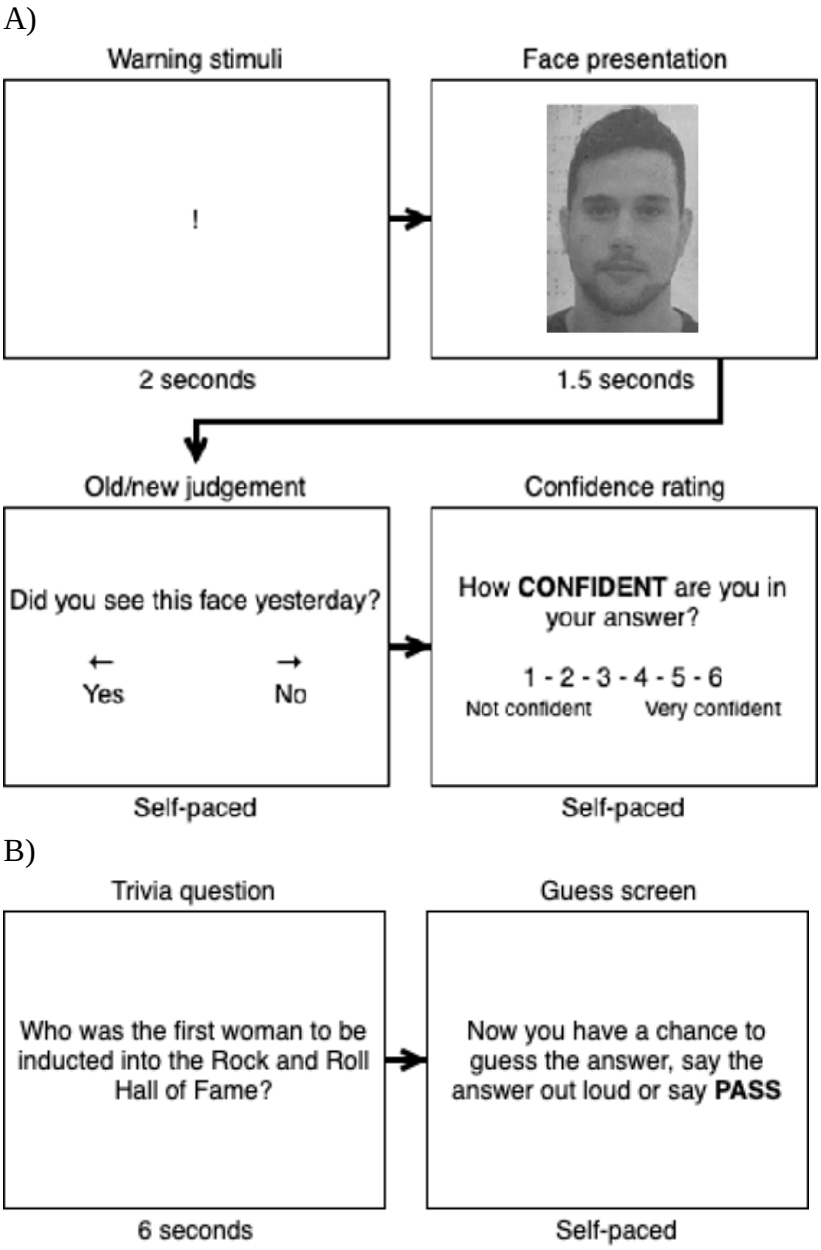

Figure 2. Memory tests during Session 2. The order of the tests was counterbalanced across age group and condition. A) Face recognition test in which participants identified old faces from the Session 1 encoding task. B) Trivia recall test in which participants guessed answers to trivia questions aloud while the experimenter entered their responses.

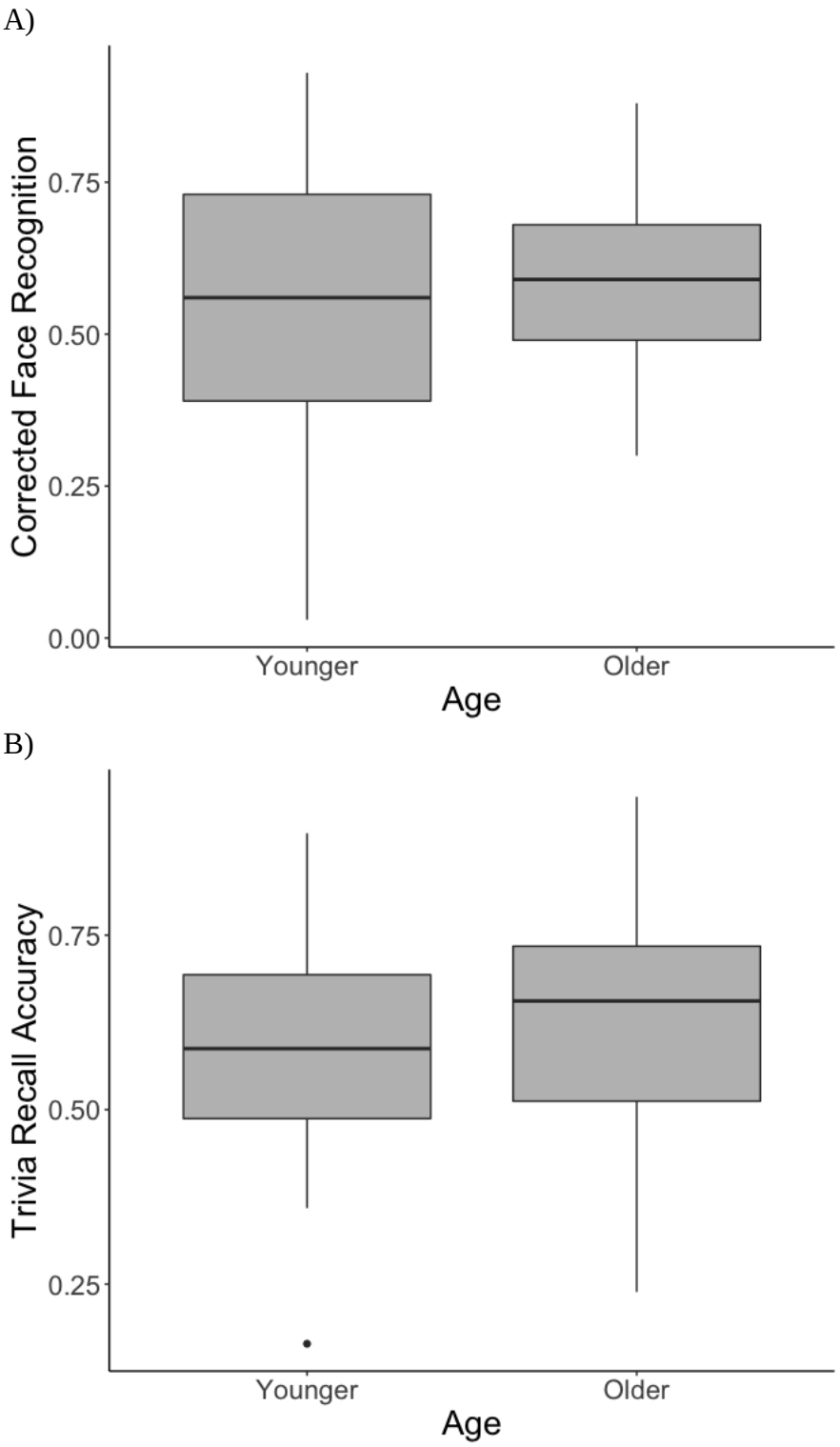

Figure 3. A) Older and younger adult performance on the face recognition task. B) Older and younger adult performance on the trivia recall task. Error bars represent standard error of the mean.

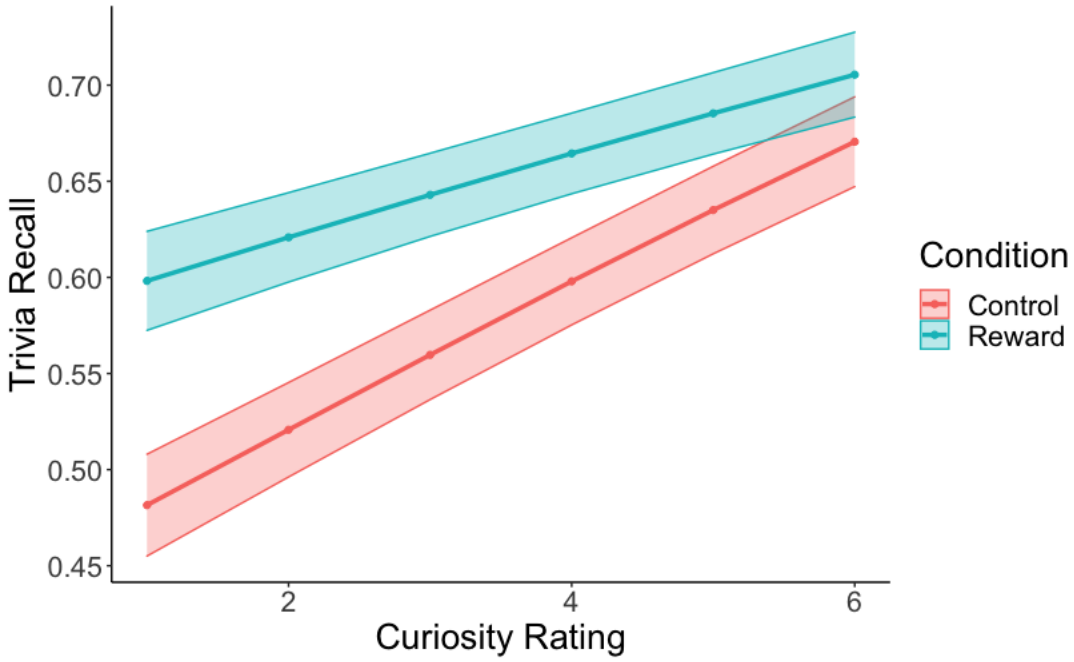

Figure 4. Predicted probability of correct trivia recall according to curiosity rating and condition. While the extrinsic reward condition boosts the probability of correct recall of low-curiosity information, this boost almost disappears for high-curiosity information. In other words, answers were just as likely to be recalled when motivated by extrinsic reward or intrinsic curiosity. Confidence bands represent standard error of the mean.

Appendix A

List of trivia items used:

Trivia Question	Answer
“Arco iris” is the Spanish term for what natural phenomenon?	Rainbow
A couple celebrating their crystal wedding anniversary have been married for how many years?	15
A goat sucker is what type of creature?	A bird
A passive two-terminal electrical component that produces electrical resistance in a circuit called?	A resistor
A phlebotomist extracts what from the human body?	Blood
A poke bowl is a diced raw fish dish that originated in which U.S. state?	Hawaii
A Shakespearean sonnet consists of how many lines?	14
A typical mayfly lives for how many days?	One
Al Gore was elected Senator for what state in 1985?	Tennessee
Andrew Carnegie developed the iron and steel industry in which city?	Pittsburgh
Bogota is the high altitude capital of which country?	Colombia
By law, what is banned in Japanese restaurants?	Japan
By what name is the groundnut better known as?	Peanut
Come as You Are, a song by the grunge band Nirvana was released on which album?	Nevermind
Dendrophobia is the fear of what?	Trees
Emerald is the birthstone for which month?	May
Father's Day was first celebrated in which country?	USA
Giorgio Armani trained for which profession although he didn't qualify?	Doctor
Granadilla is another name for which fruit?	Passionfruit
Hale-Bopp is classified as which type of small Solar System body?	Comet
How many letters are there in the German alphabet?	30
How many points does the maple leaf on the Canadian flag have?	11
How many red stripes are there on the United States flag?	7
How many squares are on a standard chessboard?	64
How many symphonies did Beethoven compose?	9
How many times zones does Canada have within it?	6
How many U.S. states border the Gulf of Mexico?	Five
How many years were there between the two Los Angeles Olympics?	52
How may dots are there on two dice?	42
Ice hockey pucks are made from what material?	Vulcanized rubber
In 2011, which country hosted a Formula 1 Race for the first time?	India

In boxing, what is the term for an illegal punch to the back of the head or base of the skull?	Rabbit Punch
In British mythology, who were Gog and Magog?	Giants
In economics, what does the letter F stand for in IMF?	Fund
In our solar system, which planet has the shortest day?	Jupiter
In square miles, how big is Lake Ontario?	7,550.00
In the 1700's, what did some residents of London purchase to avoid going to hell?	Insurance
In the classic board game Monopoly, how much does it cost to buy a railroad?	$200
In the human body what is the hallux?	Big toe
In the United States and Canada, one ton is a unit of measure that contains how many pounds?	2000
In what country did Gordon Ramsay open his first restaurant in 2007?	Ireland
In what country was the first written account of children using the phrase “trick or treat” on Halloween?	Canada
In what country were checkers invented?	Egypt
In what country would you find large ancient geoglyphs known as the the Nasca Lines?	Peru
In what sport does a jammer score a point for each opponent she skates past?	Roller Derby
In what year was Instagram launched?	2010
In what year was Stehpen Harper first elected as Prime Minister?	2006
In which branch of the arts is Katherine Dunham famous?	Ballet
In which country did cheddar cheese originate?	England
In which country is the Simpson Desert found?	Australia
In which country is the world's largest McDonald's restaurant?	United States
In which month of the year is Battle of Britain week?	September
In which season do most burglaries take place?	Winter
In which sport do the Lakers and Clippers have the same home arena?	Basketball
In which Tennessee city is it illegal to lasso fish?	Knoxville
In which US state is John F Kennedy buried?	Virginia
Jack the Ripper is the name given to an unidentified serial killer that terrorized what city in 1888?	London, England
Karakul, Texel and Romney Marsh are different kinds of what?	Sheep
Lagnoperissia is a fancy name for what sexual condition?	Nymphomania
Marxist revolutionary Che Guevara was born in what country?	Argentina
Most electrogenic fish are also what?	Electroreceptive
Nariyal is the Indian term for which nut?	Coconut
Olympia is the capital city of which U.S. state?	Washington
On Sunday, in Columbus Ohio, it is illegal to sell what?	Cornflakes

On the Apollo 11 moon mission, which astronaut stayed aloft in the command module while Neil Armstrong and Buzz Aldrin walked on the moon?	Michael Collins
On what week do most auto accidents happen?	Saturday
Papua New Guinea is bordered by which country to the west?	Indonesia
Robert Gallo was one of the pioneers n the identification of which virus?	HIV
Sika, fallow, and Roe, are what types of animal?	Deer
Someone who suffers from oneirophobia is scared of what?	Dreams
Sriracha is type of hot sauce named after a city located in what country?	Thailand
The aardvark is native to which continent?	Africa
The American musician Little Walter was associated with which instrument?	Harmonica
The chemist Alfred Nobel made his money by inventing what?	Dynamite
The expression “oy vey” comes from what language?	Yiddish
The famous American writer Samuel Langhorne Clemens is better known by what pen name?	Mark Twain
The first film star to appear on a postage stamp was who?	Grace Kelly
The Gobi Desert is primarily situated in which country?	Mongolia
The Hound of the Baskervilles is a crime novel featuring which fictional detective?	Sherlock Holmes
The May Queen, Wisley Crab, Lane's Prince Albert and Foxwhelps are all species of what?	Apple
The men’s magazine GQ was formerly known by what longer name?	Gentlemen's Quarterly
The most Asian elephants to be found in their natural habitat can be found in what country?	India
The Principality of Monaco is a sovereign city-state bordered on three sides by which country?	France
The study of birds eggs is called what?	Oology
The United States Supreme Court consists of how many judges?	9
The vehicle manufacturer Volvo was founded in what country?	Sweden
The world’s fastest growing plant is a species of what?	Bamboo
Unleavened bread or matzo, used for the Jewish feast of Passover, does not include what?	Yeast
What 20th-century conflict was dubbed the "forgotten war" despite 54,246 U.S. deaths?	The Korean War
What are the small indentations on a golf ball called?	Dimples
What brave-hearted Scottish patriot led soldiers to a defeat of the English at the Battle of Cambuskenneth in 1297?	Wiliam Wallace
What breed of horse is best known for its use in racing?	Thoroughbred
What California city did the last Pony Express ride end in?	Sacramento
What chemical element gives the blood of a lobster a bluish tint?	Copper

What city had the first public school, college and newspaper in the thirteen British colonies?	Boston
What colour is a giraffe's tongue?	Black
What colour jersey is worn by the winners of each stage of the Tour De France?	Yellow
What continent is cut into two fairly equal halves by the Tropic of Capricorn?	Australia
What continent is subjected to the world's largest ozone hole?	Antarctica
What country gave Florida to the USA in 1891?	Spain
What country was formerly known as Abyssinia?	Ehtiopia
What did Joseph Priesley discover in 1774?	Oxygen
What did people in the middle ages throw at the bride and groom?	Eggs
What diet drink was hyped by Coca-Cola for having only only calorie, in 1963?	Tab
What do doctors look at through an ophthalmoscope?	The eye
What do you call an angle more than 90 degrees and less than 180 degrees?	Obtuse
What do you call the smell which wine gives off?	Bouquet
What does a philatelist collect?	Stamps
What element begins with the letter "K"?	Krypton
What explorer introduced Italians to spaghetti in the 14th century?	Marco Polo
What explorer introduced pigs to North America?	Christopher Columbus
What flavour is cointreau?	Orange
What flightless bird is featured on New Zealand's one dollar coin?	Kiwi
What F-word is defined in physics as a "nuclear reaction in which nuclei combine to form more massive nuclei"?	Fusion
What Greek mathematician is considered the founder and father of Geometry?	Euclid
What group of Pacific islands did Japan attack the day after Pearl Harbor?	The Philippines
What holiday, celebrated December 26 to January 1, is named after the Swahili word for "first"?	Kwanzaa
What insect accurately indicates the air temperature?	Cricket
What is the common term for the tennis ailment "lateral humeral epicondylitis"?	Tennis Elbow
What is a group of a Jellyfish called?	A smuck
What is another name for the bird Didus Ineptus?	The Dodo
What is Bono's real name?	Paul Hewson
What is called when a player scores two goals in a game of soccer?	A brace
What is rum distilled from?	Sugar cane
What is someone who shoes horses called?	A farrier
What is the capital city of Canada's Yukon territory?	Whitehorse

What is the capital of Saskatchewan?	Regina
What is the English translation for the name of the German automaker Volkswagen?	People's car
What is the fastest animal in the world?	Peregrine Falcon
What is the heaviest naturally occurring element found on Earth?	Uranium
What is the largest city in Alabama?	Birmingham
What is the largest country in Central America?	Nicaragua
What is the largest freshwater lake in the World?	Lake Superior
What is the largest sea in the world?	Philippine Sea
What is the least popular month for U.S. weddings?	January
What is the most common non-contagious disease in the world?	Tooth decay
What is the most purchased grocery item in Canada?	Kraft Dinner
What is the most widely eaten fish in the world?	Herring
What is the name for a collection of frogs?	Army
What is the name for meteoroids that survive entry through the atmosphere and reach Earth’s surface?	Meteorites
What is the name for the offspring of a male donkey and a female horse?”	Mule
What is the name for the upper arm bone found in humans?	Humerus
What is the name of the dog from the 1960s television cartoon The Jetsons?	Astro
What is the name used for the study of earthquakes?	Seismology
What is the official language of Greenland?	Greenlandic
What is the only bird known to fly backwards?	Hummingbird
What is the only word in English ending in the letters 'mt'?	Dreamt
What is the plastic sheath at the end of a shoelace called?	An Aglet
What is the shallowest ocean in the world?	Arctic Ocean
What is the wobbly red piece of flesh under the beak of a turkey?	A wattle
What is Woody Harrelson's middle name?	Tracy
What Italian astronomer invented the thermometer in 1592?	Galilelo
What item is banned only during Halloween from 12am October 31st to 12pm November 1st in Hollywood California?	Silly string
What kind of animal is the emblem of the US republican political party?	Elephant
What kind of bulbs were once exchanged as a form of currency?	Tulips
What kind of plant does the Colorado beetle attack?	Potato
What land mammal other than humans has the longest lifespan?	Elephant
What measure of energy comes from the Latin word meaning “heat”?	The calorie
What method of underwater detection is short for “sound navigation and ranging”?	Sonar

What nation produces two thirds of the world's vanilla?	Madagascar
What nation was bounced from the Organization of American States in 1962?	Cuba
What nutty legume accounts for one sixth of the world’s vegetable oil production?	The peanut
What physicist’s last words were not understood because his nurse did not speak German?	Albert Einstein
What planet is closest in size to our moon?	Mercury
What popular drink did a Dutch medical professor produce in his lab when trying to come up with a blood cleanser that could be sold in drugstores?	Gin
What Spanish artist said he would eat his wife when she died?	Salvador Dali
What spiny venous fish, common in home aquariums, has become an invasive species in the Caribbean Sea and U.S. Atlantic coastal waters?	Lionfish
What television host quipped at his 1990 wedding, “The answer is… yes”?	Alex Trebek
What type of animal produces a material called gossamer?	Spider
What type of elephant has the biggest ears?	African
What type of food is a"hen of the woods"?	A mushroom
What type of tree gives us prunes?	Plum tree
What unit of electrical power is equal to one joule per second?	The Watt
What was featured in the first TV commercial advertising a toy?	Mr. Potato Head
What was invented in the 1800s and sold as a diarrhea cure?	Tomato Ketchup
What was Robert Redford's first movie?	War Hunt
What was the first commercially manufactured breakfast cereal?	Shredded Wheat
What was the first organ successfully transplanted from a cadaver to a live person?	A kidney
What was the first planet to be discovered using the telescope, in 1781?	Uranus
What’s short for “binary digit”?	Bit
What’s the only fish that produces real caviar, according to the FDA?	Sturgeon
What’s the only metal that’s not a solid at room temperature?	Mercury
What's the ballet term for a 360-degree turn on one foot?	Pirouette
When referring to an establishment that sells alcoholic drinks, what is the word “pub” short for?	Public House
When there are two full moons in the same month, what is the second called?	Blue Moon
When was the website Facebook launched?	2004
Where did the pineapple plant originate?	South America
Where is the Suez Canal located?	Egypt
Where is the worlds largest supply of fresh water?	Brazil
Where would you find the Sea of Tranquility?	The moon
Which 90’s movie soundtrack is the best-selling soundtrack of all time?	The Bodyguard

Which American author wrote the non-fiction novel “In Cold Blood”?	Truman Capote
Which atmospheric gas is the most common?	Nitrogen
Which city had the most restaurants per capita in Canada?	Montreal
Which country has more tractors per capita, Canada, Iceland or Japan?	Iceland
Which country has not fought a war since 1814?	Sweden
Which country is known as the Pearl of Africa?	Uganda
Which famous lady participated in the opening of Walt Disney's first European them park, outside of Paris, in 1992?	Cher
Which fictional character was also known as Lord Greystoke?	Tarzan
Which instrument did Louis Armstrong play?	Trumpet
Which is the only mammal that can't jump?	Elephant
Which province is home to Canada's tallest mountain?	Yukon
Which scientist is considered the father of modern genetics?	Gregor Mendel
Which type of semi aquatic animal is a lutra-lutra?	An otter
Which U.S. president issued the Emancipation Proclamation?	Abraham Lincoln
Which U.S. President made the first telephone call to the moon?	Richard Nixon
Which US President was inaugurated in 1969?	Richard Nixon
Which vitamin is also known as pantothenic acid?	B5
Which was the first nation to give women the right to vote?	New Zealand
Who created Bugs Bunny?	Tex Avery
Who had a 1960s No. 1 hit with 'The Lion Sleeps Tonight'?	The Tokens
Who had a big 80s No 1 with Every Breath You Take?	The Police
Who holds the record for the most home runs in a single major league baseball season?	Barry Bonds
Who invented the rabies vaccination?	Louis Pasteur
Who is the lead singer for the rock band Guns N’ Roses?	Axl Rose
Who preceded Ronald Reagan as American president?	Jimmy Carter
Who said, 'Money is like an arm or a leg, use it or lose it'?	Henry Ford
Who said: "I'm the president of the United States and I'm not going to eat any more broccoli"?	George Bush
Who succeeded Nixon as President of the USA in 1974.	Ford
Who was prime minister before Stephen Harper?	Jean Chrétien
Who was the first boxer to regain a lost world heavyweight title?	Floyd Patterson
Who was the first democratically-elected president of Russia?	Boris Yeltsin
Who was the first female Prime Minister of a European country?	Margaret Thatcher
Who was the first woman to be inducted into the Rock and Roll Hall of Fame?	Aretha Franklin

Who was the Greek god of wine?	Dionysus
Who was the oldest member of the rock band The Beatles?	Ringo Starr
Who was the star of the popular 80s crime drama Magnum P.I.?	Tom Selleck
Who won more Academy Awards in his lifetime than any other person?	Walt Disney
Who wrote the Great Gatsby?	F Scott Fitzgerald.
Who wrote the novel East Of Eden?	John Steinbeck
With twelve Oscar nominations and three wins, who is the most nominated male actor in Academy Awards history?	Jack Nicholson
You're most likely to see a penumbra during what?	An Eclipse
What came after "The Brady" in the sitcom title?	Bunch
What did teenager Anne Frank leave behind that was published after her death?	Diary
What is the NHL?	National Hockey League
What does the F stand for in FBI?	Federal
The US declared war on which country after the bombing of Pearl Harbor?	Japan
Which shoe company did Michael Jordan famously promote?	Nike
"The Fresh Prince of" *where* was the subject of a sitcom of 140+ shows?	Bel Air
Which state is called the Golden state?	California
What colour is the M in McDonald's?	Yellow
In fiction, what is the last name of Dr. Hannibal--the Cannibal?	Lecter
What is the Aloha State?	Hawaii
With which sport is Babe Ruth associated?	Baseball
Who recorded the album Dark Side of the Moon?	Pink Floyd
"My heart will go on" came from which movie?	Titanic
Who played Rachel Green in Friends?	Jennifer Aniston
In baseball, where do the Blue Jays come from?	Toronto
What is the main color on the chinese flag?	Red
What does the C stand for in LCD?	Crystal
On a computer keyboard, what letter is between Q and E?	W
What is the postal abbreviation for California?	CA
Which Buzz appeared in Toy Story?	Lightyear
"Circle of Life" came from which film?	Lion King
The sale of what was prohibited in America during prohibition?	Alcohol
Which state is called the Empire State?	New York
What sort of creature appeared in "Free Willy"?	Whale
In football, what position is QB?	Quarterback
What was the favorite food of the Teenage Mutant Ninja Turtles?	Pizza
What color are the stars on the United States of America flag?	White

Which anti-impotence treatment became the 90s fastest-selling prescription drug?	Viagra
What kind of codes did American supermarkets introduce in the mid 70s?	Bar Codes
How are the Motion Picture Academy Awards also known?	Oscars
Which language apart from English is an official language of Canada?	French
In which country is an Afghani a unit of currency?	Afghanistan
Ottawa is which country's capital?	Canada
What is the Great Barrier Reef made from?	Coral
Which ocean is off the Californian coast?	Pacific
What day in November is Rememberance Day?	11th
How many friends are there in sitcom "Friends"?	Six
Who played Jack in Titanic?	Leonardo DiCaprio
Walt Disney's famous deer was named what?	Bambi
What is the most popular sport in Canada?	Ice Hockey
What is the slang name for a 1 dollar Canadian coin?	Loonie
What is the national animal of Canada?	Beaver
What kind of leaf is on the Canadian flag?	Maple
What is the name for Canadian bacon?	Peameal
What is the name for the most popular Canadian coffee chain?	Tim Horton's
Which Canadian Prime Minister was elected in 2015?	Justin Trudeau
What is the tallest free-standing structure in Canada?	CN Tower
What is the name for the dish made with french fries, gravy, and cheese curds?	Poutine
Which Canadian province is majority French-speaking?	Quebec