Emotion-Enhanced Binding of Numerical Information in Younger and Older Adults

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Abstract

There are documented deficits in older adults' abilities to bind numerical information to other types of information, perhaps due to the arbitrariness and specificity of numbers. While some studies have found that memory for associative details is more accurate for emotionally-salient information than emotionally-neutral information, other research has failed to find this benefit. We investigated whether older adults' associative memory deficit for numerical information may be reduced when information is encountered in an emotionally-salient context. We presented younger and older adults with numerical information in a sentence that was either emotionally positive, negative or neutral and later asked them to recall the numbers when given their corresponding context. While younger adults recalled more information than older adults, both groups of participants recalled more numbers in emotionally-valenced as compared to emotionally-neutral contexts, with the most accurate memory for numbers in the highly-arousing negative context. Both groups of participants also rated the negative information as more important and easier to remember. These results provide evidence that emotion-enhanced binding is consistent between younger and older adults in some contexts and that memory for specific and arbitrary numerical information may be more accurate in an emotionally-salient as compared to emotionally-neutral context.

Keywords: associative memory, emotional valence, numerical memory

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Numerical information is ever present in daily life. What time was your meeting scheduled? How much did gas cost this week? How many milligrams of that medication were you advised to take? In many of these situations, it is often advantageous (or even necessary) to remember both the numerical value *and* the specific context in which it was encountered – that is, it is valuable to know that the cheapest gas this week was $2.20 at the gas station near your house, not the one near work, or that you should take 500 mg of aspirin, not acetaminophen. The ability to remember these linked or bound pieces of information is a form of associative memory. Prior research has demonstrated that older adults' episodic memory deficits are largest when multiple features are required to be linked in memory, as compared to memory for those features individually (Naveh-Benjamin, 2000). This associative deficit has been replicated in a variety of domains including verbal memory (Naveh-Benjamin, 2000), visuospatial memory (Thomas, Bonura, Taylor, & Brunyé, 2012; Siegel & Castel, 2018) and, importantly in the context of the current study, when numerical information is to-be-remembered (Castel, 2005, 2007).

Numbers may be particularly difficult to associate in memory due to their specific and arbitrary nature. It is often important to remember exact numerical information, as opposed to a gist-based representation, in order to maximize potential gains and minimize potential consequences (e.g., remembering that you owe your insurance company exactly $125 or that you need to use exactly 1 ½ cups of flour in the recipe). Further, there may not be any meaningful reason as to why a number is encountered in a particular context. In fact, that number may even vary when encountered in a different context (e.g., milk may cost $2.99 at one market, but $3.99 at another). Given these factors and the prevalence of numbers in the environment, specific numerical information may be particularly difficult to remember.

In the lab, studies investigating associative memory for numerical information have consistently revealed age-related binding deficits. Castel (2005) found that when presented with grocery items and their corresponding price younger adults correctly recalled more of the items' exact prices at test, but only when the prices were unusual and not consistent with the real-world market value of the item (e.g., a carton of eggs for $15.99). When the prices were representative of the general market value of the item, however, age-related differences in price recall were eliminated, suggesting that when older adults are able to rely on prior knowledge and schemas, age-related associative memory deficits may be attenuated. In a similar paradigm, Castel (2007) found that older adults who had extensive prior experience with numerical information (i.e., retired bookkeepers and accountants) were much more likely to accurately recall the number in a sentence like "26 cherries in a bowl" relative to another group of non-expert older adults. These results suggest that while age-related associative deficits are certainly present for numerical information, the ability to rely on schematic knowledge and expertise may reduce these deficits.

One factor that may influence older adults' attention and subsequent memory is the emotional valence of the information. According to socioemotional selectivity theory, there is a change in the goals that we pursue as we age – in early adulthood we pursue knowledge acquisition and, as we get older, we shift our focus to emotion regulation (Carstensen, Isaacowitz, & Charles, 1999). A number of empirical studies have revealed that because older adults value emotional (and specifically positive) information, their memory for this type of information is relatively spared from age-related decline in some contexts, and perhaps even enhanced with age (Carstensen & Mikels, 2005; Charles, Mather, & Carstensen, 2003; Fung & Carstensen, 2003). Given that memory for emotional information is somewhat preserved despite declines in overall memory raises intriguing questions about whether this ability could be

recruited to counter other weakened areas of memory, such as memory for arbitrary numerical information.

Prior research investigating the effects of emotional arousal on associative memory have been inconclusive. Some studies found that associative memory benefitted from emotional arousal, termed arousal-enhanced binding (Mather & Nesmith, 2008). This effect has been demonstrated with a variety of materials including emotional words (Doerksen & Shimamura, 2001; Kensinger & Corkin, 2003) and pictures (Kensinger, Garoff-Eaton, & Schacter, 2006; Mather & Nesmith, 2008; for a review, see Mather & Sutherland, 2011). In each of these studies, the presence of an emotionally-salient stimulus enhanced memory for associated contextual details, which was not the case when the stimulus was emotionally-neutral. Importantly, this enhancement was found for both positive and negative stimuli, suggesting that the emotion in general rather than the particular valence was producing this memorial benefit. The arousal-enhanced binding effect has been attributed to an increase in focused attention on stimuli that are emotionally-arousing, leading to better subsequent memory for that information and its associated details (Mather & Nesmith, 2008).

However, this beneficial effect of emotionally-salient information is not ubiquitous. Other work has found no benefit for, or even an impairment in, the binding of emotionally-arousing information (Madan, Caplan, Lau, & Fujiwara, 2012; Naveh-Benjamin, Maddox, Jones, Old, & Kilb, 2012). These studies, utilizing words pairs of mixed valences, found an increase in individual item memory for positive and negative information consistent with prior research, but did not find that memory associations containing emotionally-salient stimuli were enhanced more than those containing emotionally-neutral stimuli. This was the case for both younger and older adults (Naveh-Benjamin et al., 2012). The proposed explanation for these results again relies on the effect of emotional salience on attention: the emotionally-arousing stimuli drew

more attention than the emotionally-neutral stimuli, which increased memory for that

emotionally-arousing information, but drew attention away from the other emotionally-neutral

stimulus and the association between the two stimuli. In this interpretation, the emotional nature

of the information enhanced memory for that information by biasing attentional resources

towards it. However, this may have also hindered the binding of that information with other non-

emotional associated information. As such, there exists a debate as to whether emotional arousal

biases attention in a manner that enhances or impairs memory for associated information. It is

important to note, however, that none of these studies involved the binding of numerical

information (on its own, a form of emotionally-neutral information). In light of these mixed

findings, the goal of the current study was to determine whether the presence of an emotionally-

salient context may reduce older adults' impairment in forming and remembering associations

between numerical information and its context.

The Current Study

Prior research has revealed older adults' disproportionate associative memory deficits,

including when specific and arbitrary numbers are present (Castel, 2005, 2007; Castel,

McGillivray, & Worden, 2013). Other work has provided evidence for preserved memory in old

age for valuable and emotional information (Carstensen & Mikels, 2005; Castel, 2008) and

investigated how that information may be remembered in an associative context (Mather &

Nesmith, 2008; Naveh-Benjamin et al., 2012). However, little research has been conducted on

how these factors might interact when numerical information is present – that is, whether the

presence of an emotionally-meaningful context might enhance or reduce associative memory for

numbers. The presence of an emotionally-salient context may draw participants' attention and

evoke enhanced elaborations and associations which may lead to more accurate binding of the

numerical information to its source relative to an emotionally-neutral context, consistent with

prior research demonstrating arousal-enhanced binding (Mather & Nesmith, 2008). Further,

older adults may demonstrate a positivity bias in their memory such that their associative

memory may be equivalent to that of younger adults for emotional, but especially positive

information, consistent with prior work (Carstensen & Mikels, 2005; Charles et al., 2003; Fung

& Carstensen, 2003). On the other hand, the emotional arousal produced by the context may

impair associative binding by drawing attentional resources away from the to-be-learned

associations (Naveh-Benjamin et al., 2012), resulting in worse memory for emotional relative to

neutral sentences.

In the current study, we asked younger and older adults to study sentences containing

numerical information presented in either a negative, neutral, or positive context and later tested

their memory for the numerical information when presented with the previously-studied

sentence. Consistent with previous research, we expected that younger adults would be more

accurate in their associative memory overall than older adults. We also expected that numerical

information presented in an emotional context would be better remembered than information in a

neutral context. We were further interested in whether the varying emotional contexts would

differentially influence younger and older adults' associative memory (e.g., that older adults may

exhibit a positivity bias).

Method

Participants

The participants were 31 younger adults (20 females) and 31 older adults (17 females).

Younger adult participants were University of California, Los Angeles (UCLA) undergraduate

students who ranged in age from 17 to 28 years ($M = 20.26$, $SD = 2.03$) and received course

credit for their participation. Older adult participants were recruited from the local community,

ranged in age from 60 to 88 years ($M = 72.71$, $SD = 7.36$), and were compensated \$10 per hour

plus parking expenses for their participation. At the time of participation, younger adults had completed an average of 13.94 years of education ($SD = 0.80$), while older adults had completed an average of 16.00 years of education ($SD = 1.69$). All older adult participants were in self-reported good health and did not report any significant visual impairment.

Materials

The materials in this study consisted of 24 sentences containing one or more numerical values in an emotionally-valenced or emotionally-neutral context (see Table 1 for the full list of materials used in the current study). Unlike previous work which has utilized word pairs (e.g., Madan et al., 2012; Naveh-Benjamin et al., 2012) or pictures in locations (e.g., Mather et al., 2006; Nashiro & Mather, 2011) to examine associative emotional memory, the current study sought to use more realistic stimuli which may provide a richer context more akin to real-world scenarios than other previous lab-based studies. Eight sentences were categorized as negatively-valenced (e.g., "The man died while climbing a mountain at an altitude of [number] feet"), eight were categorized as neutrally-valenced (e.g., "The shipping freighter carried [number] pounds of cargo"), and were eight categorized as positively-valenced (e.g., "The man donated his entire $[number] savings to the charity"). These sentences were normed using a separate group of online participants who provided emotional valence and arousal ratings which is described below. The type of number in each sentence varied (e.g., currencies, times, quantities, etc.). Each sentence had fixed numerical values associated with it. The number of digits in each sentence ranged from two to six ($M = 3.38$, $SD = 1.41$) and each valence type contained six sentences with four or fewer total digits and two sentences with five or more total digits. Sentences were also categorized as low or high arousal using a median split based on arousal ratings within each valence category. That is, for each valence, the four sentences with the highest arousal ratings were considered "high arousal" and the four sentences with the four lowest ratings were

considered "low arousal". The materials were constructed such that the average number of digits per sentence within each valence were not statistically different (negative: $M = 3.25$, $SD = 1.49$, neutral: $M = 3.38$, $SD = 1.19$, positive: $M = 3.50$, $SD = 1.69$), $F(2, 21) = 0.06$, $p = .94$, $\eta^2 = .01$.

Normed sentence ratings. To ensure that sentences were accurately categorized by valence, ratings were collected through Amazon Mechanical Turk (MTurk). MTurk is an online marketplace in which workers (participants) complete human intelligence tasks (HITs) for compensation. Prior work investigating MTurk suggests that it is as reliable as traditional, in-lab testing, strengthening its efficacy as a psychological research tool (Buhrmester, Kwang, & Gosling, 2011; Paolacci, Chandler, & Ipeirotis, 2010). For the current study, a HIT was created to collect normed valence, arousal, importance, and difficulty ratings from younger and older workers.

We collected ratings from 147 workers located in the United States: younger adults ($n = 80$, $n_{female} = 41$, $M_{age} = 23.77$, $SD_{age} = 2.58$, age range: 20-39 years) and older adults ($n = 67$, $n_{female} = 39$, $M_{age} = 65.13$, $SD_{age} = 4.68$, age range: 61-84 years). Workers were instructed that they would be presented with a series of sentences containing numerical information and provide the following ratings about their reactions when reading each sentence: emotional valence from 1 (*very negative*) to 7 (*very positive*), arousal from 1 (*very calm*) to 7 (*very excited*), importance ("If you saw this sentence in the news, how important would it be to remember?") from 1 (*not at all important*) to 7 (*very important*), and difficulty ("If you saw this sentence in the news, how difficult would it be to remember it (including the exact number) at a later point?") from 1 (*very easy*) to 7 (*very difficult*). Participants made these ratings for each of the 24 sentences in a sequential manner and were then compensated $2.00 for the approximately 20 min HIT.

The current study was primarily interested in the valence and arousal ratings provided by participants to ensure the sentences utilized were accurately categorized by emotional valence

and that arousal ratings were consistent with previous findings. These valence and arousal

ratings, along with the other obtained ratings, are presented in Table 2. Average valence ratings

for negative sentences ranged from 1.99 to 2.86, neutral sentences ranged from 3.90 to 4.24, and

positive sentences ranged from 5.22 to 5.67. To determine if the provided valence ratings were

significantly different for each category and if these differences were consistent across age

groups, we conducted a 2 (Age: younger adults, older adults) x 3 (Valence: negative, neutral,

positive) repeated-measures analysis of variance (ANOVA) on the valence ratings provided by

the MTurk workers. We found a significant main effect of valence category, $F(2, 144) = 211.88$,

$p < .001$, $\eta^2 = .75$. Follow-up comparisons using paired-samples t-tests with a Bonferroni

correction indicated that sentences in the negative valence condition were rated significantly

lower on the valence scale ($M = 2.39$, $SD = 1.06$) than the neutral valence condition ($M = 4.08$,

$SD = 0.57$), $t(146) = 18.62$, $p < .001$, and the positive valence condition ($M = 5.46$, $SD = 0.94$),

$t(146) = 20.64$, $p < .001$. Further, neutral valence sentences were rated lower on the valence scale

than positive sentences, $t(146) = 18.09$, $p < .001$. The ANOVA also revealed no significant main

effect of age group, $F(1, 45) = 0.72$, $p = .40$, $\eta^2 = .01$, and no interaction between age group and

valence, $F(2, 144) = 0.80$, $p = .45$, $\eta^2 = .002$. As such, these ratings suggest that the sentences

used as stimuli in the current study were categorized accurately according to valence and that

these valence ratings were consistent between younger and older adults.

        The same analysis was conducted on arousal ratings provided by participants. There was

a significant effect of valence category on arousal ratings, $F(2, 290) = 83.81$, $p < .001$, $\eta^2 = .37$.

Follow-up comparisons using paired-samples t-tests with a Bonferroni correction revealed that

sentences in the negative valence condition ($M = 3.84$, $SD = 1.23$) were rated significantly

higher on the arousal scale than neutral valence sentences ($M = 2.85$, $SD = 1.14$), $t(146) = 8.58$, p

$< .001$. Additionally, positive valence sentences ($M = 4.18$, $SD = 1.25$) were rated significantly

higher than neutral valence sentences, $t(146) = 13.50$, $p < .001$, and negative valence sentences, $t(146) = 3.19$, $p = .01$. The ANOVA also revealed no significant main effect of age group, $F(1, 145) = 2.14$, $p = .15$, $\eta^2 = .02$, and no interaction between age group and valence, $F(2, 290) = 1.96$, $p = .14$, $\eta^2 = .01$. These analyses indicate that both the negative and positive sentences used in the current study were significantly more arousing than the neutral sentences and the positive sentences were more arousing than the negative sentences, which was consistent between age groups.

Procedure

Participants in this study were instructed that they would be presented with sentences containing various types of numerical information and that their goal would be to remember the number in its specific context. Participants were shown an example sentence in the same format as the sentences that they would later be presented (e.g., "The 56-year-old man was in the car") and were shown the format of the later test in which they would have to recall the number given the corresponding sentence (e.g., "The ___-year-old man was in the car"). Participants were further instructed to remember the numbers as accurately as possible. Participants were then shown the 24 sentences sequentially, each for 5s. The order of the presentation of the sentences was randomized for each participant. After the study period, participants completed a 1 min filler task in which they were asked to remember and type out all the food they ate in the prior 24 hours into a textbox on the screen. This filler task was included to ensure that participants could not rehearse information after the study period was completed.

After the minute expired, participants began the test phase in which a sentence was presented without its corresponding number which they were then asked to recall by typing the number into the blank space. Given that participants knew their memory for the numbers would be tested, this represents an intentional test of associative binding, in contrast to prior work in

which participants are either unaware they will be tested or do not know which specific feature

or item will be queried (e.g., Madan et al., 2012). Sentences during the test phase were also

sequentially presented in a random order which did not correspond with the order in which the

sentences were presented during the study phase. Participants were required to submit a response

for each sentence and were encouraged to guess if they were not sure about the numerical value.

Participants did not receive explicit feedback on their performance during the test phase.

After participants responded to all 24 sentences, they were asked to make subjective

judgments about each sentence. Participants were again sequentially presented with the sentences

(with the corresponding numerical values now present) and were asked "How important was it to

remember the number in this sentence?" on a scale from 1 (*not at all important*) to 7 (*very

important*) and "How easy was it to remember the number in this sentence?" on a scale from 1

(*very easy*) to 7 (*very difficult*). The experiment was completed when participants provided these

two ratings for all 24 sentences. All materials and procedures used in this study were approved

by the UCLA Institutional Review Board.

Results

Number Recall Accuracy

Figure 1 depicts number recall accuracy as a function of age group and sentence valence

and arousal. We first examined whether recall of numerical information was dependent on age,

valence, and arousal by conducting a 2 (Age group: younger adults, older adults) x 3 (Valence:

positive, neutral, negative) x 2 (Arousal: low, high) mixed-subjects analysis of variance

(ANOVA) on number recall accuracy (i.e., the proportion of sentences out of 24 in which the

correct accompanying numbers were all precisely recalled).

First, there was a main effect of age group such that younger adults ($M = .40$, $SD = .22$)

had significantly higher recall accuracy than older adults ($M = .32$, $SD = .22$), $F(1, 60) = 4.48$, *p*

= .04, η^2 = .07. Next, we found a main effect of valence, $F(2, 120) = 37.39$, $p < .001$, η^2 = .38. We conducted post-hoc follow-up paired-samples t-tests with a Bonferroni correction which revealed that recall accuracy was significantly higher in negative sentences ($M = .45$, $SD = .20$), relative to positive sentences ($M = .38$, $SD = .22$), $t(61) = 3.27$, $p = .004$, Cohen's $d = .51$, and neutral sentences ($M = .24$, $SD = .18$), $t(61) = 8.78$, $p < .001$, Cohen's $d = 1.08$. In addition, recall accuracy of numbers within positively-valenced sentences was greater than those in neutrally-valenced sentences, $t(61) = 5.52$, $p < .001$, Cohen's $d = .60$.

Finally, there was a significant interaction between valence and arousal, $F(2, 120) = 6.73$, $p = .002$, $\eta^2 = .10$. We conducted post-hoc follow-up paired-samples t-tests with a Bonferroni correction to examine the effect of arousal on number recall accuracy within each valence category. For negative valence sentences, high arousal sentences ($M = .52$, $SD = .29$) were recalled significantly more accurately than low arousal sentences ($M = .26$, $SD = .21$), $t(61) = 3.50$, $p < .001$, Cohen's $d = .44$. However, there was no significant difference between high arousal and low arousal sentences in the neutral ($M_{high} = .22$, $SD_{high} = .25$, $M_{low} = .26$, $SD_{low} = .21$) and positive valence ($M_{high} = .35$, $SD_{high} = .26$, $M_{low} = .37$, $SD_{low} = .27$) categories, $t(61) = 1.25$, $p = .65$, and $t(61) = 0.38$, $p > .99$, respectively. In terms of insignificant effects, there was no main effect of arousal, $F(1, 60) = 1.76$, $p = .19$, $\eta^2 = .03$, no arousal by age interaction, $F(1,60) = 1.25$, $p = .27$, $\eta^2 = .02$, no valence by age interaction, $F(2, 120) = 0.51$, $p = .60$, $\eta^2 = .01$, and no three-way interaction between valence, arousal, and age, $F(2, 120) = 1.56$, $p = .22$, $\eta^2 = .02$.

We also examined a more lenient memory measure in which participants' responses were counted as correct if they fell within $\pm10\%$ of the target response (e.g., a response of 54 would be counted as correct for the sentence "The 56-year old man was in the car" as it falls within ±5.6 of the correct value). This dependent measure was analyzed as older adults may be more likely to

rely on gist-based processing and memory (Brainerd & Reyna, 2001; Gallo, Hargis, & Castel, 2019; Koutstaal, 2006; Reder, Wible, & Martin, 1986) and thus exhibit a smaller or no age-related memory deficit on this measure.

We conducted a 2 (Age group: younger adults, older adults) x 3 (Valence: positive, neutral, negative) x 2 (Arousal: low, high) mixed-subjects ANOVA on lenient number recall accuracy (recall within ±10% of the target response). In general, the pattern was largely consistent with the findings when utilizing the strict number accuracy measure in which the exact number had to be produced. However, there were two key differences produced between these analyses. Firstly, there was no longer a main effect of age group, $F(1, 59) = 1.02$, $p = .32$, $\eta^2 = .02$, such that older ($M = .40$, $SD = .20$) and younger adults ($M = .46$, $SD = .18$) were equally as accurate in their memory performance. The second difference was the disappearance of the arousal x valence interaction observed when examining strict accuracy. For lenient accuracy, there was no interaction between arousal and valence, $F(2, 118) = 1.98$, $p = .14$, $\eta^2 = .03$. However, the main effect of valence was maintained, $F(2, 118) = 29.73$, $p < .001$, $\eta^2 = .33$, with accuracy highest for negative sentences ($M = .53$, $SD = .23$) and lowest for neutral sentences ($M = .32$, $SD = .20$), with accuracy for positive sentences falling in between ($M = .43$, $SD = .23$), Bonferroni-adjusted ps $< .001$. Other than that, all other effects were consistent with those obtained when analyzing strict accuracy, with no other main effects or interactions, ps $> .42$.

This analysis examining lenient recall accuracy suggests that when using a gist-based measure, older adults were equally as accurate in their memory as younger adults, which supports well-established findings of older adults' reliance on gist-based processing (Brainerd & Reyna, 2001; Gallo et al., 2019; Koutstaal, 2006; Reder et al., 1986). Unfortunately, this more lenient scoring criterion was not sensitive enough to detect the arousal x valence interaction, which was likely eliminated due to the more liberal measure. Given that this lenient scoring

measure provides less fine-grained detail about participants' memory performance as a function of valence and arousal, the previously discussed strict memory accuracy measure will be the focus of the remaining analyses and discussion in the current study.

Importance and Difficulty Ratings

Figure 2 depicts participants' subjective ratings of the importance of each sentence differed between age group, valence, and arousal. To analyze these data, we conducted a 2 (Age group: younger adults, older adults) x 3 (Valence: positive, neutral, negative) x 2 (Arousal: low, high) mixed-subjects ANOVA on importance ratings. We found a main effect of age group, such that older adults ($M = 5.17$, $SD = 1.78$) gave higher importance ratings overall than younger adults ($M = 4.24$, $SD = 1.23$), $F(1, 60) = 6.21$, $p = .02$, $\eta^2 = .09$. We also found a main effect of valence, $F(2, 120) = 9.47$, $p < .001$, $\eta^2 = .26$. We conducted follow-up comparisons with a Bonferroni correction and found that negative sentences ($M = 5.01$, $SD = 1.36$) were rated as more important than positive sentences ($M = 4.65$, $SD = 1.51$), $t(61) = 4.14$, $p < .001$, Cohen's $d = .69$, and neutral sentences ($M = 4.45$, $SD = 1.64$), $t(61) = 6.44$, $p < .001$, Cohen's $d = .53$. There was also a significant difference between importance ratings for positive and neutral sentences, $t(61) = 2.30$, $p = .02$, Cohen's $d = .36$. There was no main effect of arousal, $F(1, 60) = 2.49$, $p = .12$, $\eta^2 = .04$, no interaction between age group and valence, $F(2, 120) = 0.29$, $p = .75$, $\eta^2 = .01$, no interaction age group and arousal, $F(1, 60) = 1.11$, $p = .30$, $\eta^2 = .02$, no interaction between valence and arousal, $F(2, 120) = 0.28$, $p = .76$, $\eta^2 = .01$, and no three-way interaction between valence, arousal, and age, $F(2, 120) = 0.30$, $p = .74$, $\eta^2 = .01$.

Figure 3 depicts participants' difficulty ratings as a function of age group, valence, and arousal. We conducted the same analysis mixed-subjects ANOVA on participants' difficulty ratings and found a main effect of valence, $F(2, 120) = 22.45$, $p < .001$, $\eta^2 = .27$. Follow-up comparisons with a Bonferroni correction revealed that neutral sentences ($M = 4.67$, $SD = 1.02$)

were rated as more difficult to remember than negative sentences ($M = 3.95$, $SD = 1.12$), $t(61) =$ 6.66, $p < .001$, Cohen's $d = .85$, and positive sentences ($M = 4.03$, $SD = 1.05$), $t(61) = 5.34$, $p <$ .001, Cohen's $d = .68$. There was no significant difference in difficult ratings between negative and positive sentences, $t(61) = 0.35$, p > .99, Cohen's $d = .85$. There was also a significant interaction between valence and arousal, $F(2, 120) = 5.10$, $p = .007$, $\eta^2 = .08$. We conducted follow-up paired-samples t-tests with a Bonferroni correction to examine the effect of arousal on difficulty ratings within each valence category. For the neutral valence category, high arousal sentences ($M = 4.91$, $SD = 1.18$) were rated as more difficult to remember than low arousal sentences ($M = 4.42$, $SD = 1.35$), $t(61) = 2.62$, $p = .03$, Cohen's $d = .33$. However, there was no significant difference in difficulty ratings between low and high arousal in the negative ($M_{high} =$ 4.01, $SD_{high} = 1.42$, $M_{low} = 4.03$, $SD_{low} = 1.41$) and positive ($M_{high} = 3.92$, $SD_{high} = 1.33$, $M_{low} =$ 4.20, $SD_{low} = 1.23$) valence categories, $t(61) = 0.09$, $p > .99$, Cohen's $d = .01$, and $t(61) = 1.64$, p $= .32$, Cohen's $d = .21$, respectively.

Finally, there was no main effect of age group, $F(1, 60) = 0.76$, $p = .39$, $\eta^2 = .01$, no main effect of arousal, $F(1, 60) = 0.29$, $p = .59$, $\eta^2 = .01$, no interaction between age group and valence, $F(2, 120) = 0.51$, $p = .60$, $\eta^2 = .01$, no interaction between age group and arousal, $F(1, 60) = 0.71$, $p = .40$, $\eta^2 = .01$, and no three-way interaction between valence, arousal, and age, $F(2, 120) = 0.50$, $p = .61$, $\eta^2 = .01$.

Correlations between Recall, Importance, and Difficulty

We also wanted to determine whether participants' recall was correlated with the number of digits in the sentence, as well as the importance and difficulty ratings provided by the participants. We computed Pearson's correlation coefficients between these measures collapsed across age groups, as well as for younger and older adults individually. Pearson's correlations for each age group and valence individually revealed a similar pattern between younger and older

adults and between the three valences and as such the collapsed analyses are presented here. There was a significant negative correlation between recall and digit length, $r = -.60$, $p = .002$, such that sentences with more digits were recalled less accurately than sentences with fewer digits. There was also a significant positive correlation between recall and importance, $r = .70$, $p < .001$, and a significant negative correlation between recall and difficulty, $r = -.97$, $p < .001$. This indicates that participants had better recall for sentences that they rated as more important and less difficult to remember than those that they rated as less important and more difficult to remember. We also found a significant negative correlation between importance and difficulty ratings, $r = -.72$, $p < .001$, such that sentences that were rated as more important were also rated as easier to remember and sentences that were rated as less important were rated as more difficult to remember. There was also a significant negative correlation between importance and digit length, $r = -.45$, $p = .03$, such that sentences with fewer digits were rated as more important than sentences with more digits. Finally, there was a significant positive correlation between difficulty and digit length, $r = .59$, $p = .002$, such that sentences with more digits were rated as more difficult to remember than sentences with fewer digits.

Correlations between Study Participants' and MTurk Workers' Ratings

One potential concern was whether importance and difficult ratings may have been influenced by participants' recall performance. That is, if participants misremembered a numerical value, when they were presented with full sentence with the correct value during the ratings phase, they may have been more likely to rate it as being more difficult to remember than one they correctly remembered. Similarly, perhaps ratings of importance were positively related to recall success, not because of the sentence's normative importance, but because participants may have rated the sentences they remembered the numerical values for as being more important. As such, we calculated the same correlations as previously described, but included the

ratings provided by the MTurk workers who did not complete a memory task and whose ratings were thus uninfluenced by any recall performance.

Pearson's correlations computed between the participants' and MTurk workers' importance ($r = .78$, $p < .001$) and difficulty ratings ($r = .77$, $p < .001$) were significantly positive. To examine how these MTurk workers' ratings correlated with participants' recall and sentence digit length, Pearson's correlations were calculated and demonstrated that there was again a significant positive correlation between participants' recall performance and MTurk workers' importance ratings, $r = .37$, $p = .04$, and a significant negative correlation between recall performance and MTurk worker's difficulty ratings, $r = -.70$, $p < .001$. We also found a significant negative correlation between MTurk workers' importance and difficulty ratings, $r = -.63$, $p < .001$. Finally, the significant positive correlation between difficulty and digit length was maintained, $r = .53$, $p = .004$. The only correlation that was not consistent was the negative correlation between importance and digit length that was not found to be significant when examining the MTurk workers' ratings, $r = -.09$, $p = .34$. As such, sentence ratings provided by participants after the memory task likely represent the sentences' normative importance and difficulty ratings that are relatively uninfluenced by their prior recall performance.

Discussion

The current study investigated how emotional valence may influence older adults' memory for numerical information. Specifically, we tested whether older adults' associative memory deficit may be reduced or eliminated when information was presented in an emotionally-salient context. We found that while memory for numerical information was more accurate in an emotional (i.e., positive and negative) context for both younger and older adults, age-related deficits still emerged for numerical information in each valence condition. Participants also recalled more numerical information when it was presented in a negative,

relative to positive, context. Importantly, arousal enhanced binding, but only in the context of negative sentences. We also found that both groups of participants rated negatively-valenced sentences as the most important and easiest to remember, while they rated neutrally-valenced sentences as the least important and hardest to remember.

Based on the results of our experiment, we found further evidence to support previous research suggesting an associative memory deficit present in old age, here extending that work to associative numerical memory (Castel, 2007; Naveh-Benjamin, 2000). These results may appear to conflict with previous work demonstrating that older adults have better memory for numbers that fit a particular schema, but worse memory for items that are schema-irrelevant like over-market grocery prices (Castel, 2005; Castel et al., 2013; Gallo et al., 2019; Soederberg Miller, 2003). In the context of the current study, older adults may have more schematic support for negative and positive sentences, as they are perhaps more likely to consume this type of information in the daily news cycle than more neutral information. That is, news stories that contain numerical information are likely to be positive or negative in nature (and thus, be considered newsworthy) rather than more mundane neutral information that is unlikely to attract much news coverage. As such, studying emotionally-valenced sentences containing numerical information may have provided older adults with greater schematic support than the neutral, non-emotional sentences.

Our results also appear to demonstrate that the positivity effect in aging (e.g., Carstensen & Mikels, 2005) may not be present in all memory tasks, and that negative information may be better remembered in some contexts for both younger and older adults. While we did not find support for the positivity effect found in other studies investigating memory for emotional information (Carstensen & Mikels, 2005; Charles et al., 2003; Fung & Carstensen, 2003), we did find a benefit of emotional over neutral contexts, suggesting that emotional valence enhances the

binding of numerical information to its context in this task for both age groups. A meta-analysis conducted by Murphy and Isaacowitz (2008) found attention- and memory-related preferences for positive and negative relative to neutral stimuli, with few age-related differences with regard to emotional valence. Importantly, in the majority of studies included in their analyses, there was no difference in magnitude between the positivity and negativity preference for older adults (cf. Reed, Chan, & Mikels, 2014). Consistent with this meta-analysis, the results from the current study indicated a preference for emotional information, indicated by both numerical recall performance and subjective ratings of importance and difficulty.

Further, our results are consistent with some prior work indicating a benefit of emotional valence on memory for associated information (Doerksen & Shimamura, 2001; Mather & Nesmith, 2008; May, Rahhal, Berry, & Leighton, 2005; Nashiro & Mather, 2011) and stand in contrast to other studies indicating no benefit or an impairment in associative memory (Madan et al., 2012; Mather et al., 2006; Naveh-Benjamin et al., 2012). Other studies that have utilized emotional word pairs as stimuli to study associative binding have found that when binding two separate unrelated items (e.g., the word pair "smile-pencil"), the emotional item hinders binding as it attracts attention to the word itself, but away from the association between the two unrelated words. In the current study, when an item (i.e., the number) is completely embedded in the context (i.e., the sentence), emotional and especially negative information served to enhance memory for the item in the sentence. As such, our results suggest that emotional valence may in fact enhance binding when numerical information is involved. Rather than draw attentional resources away from associated information, it is possible that the emotionally-salient sentences attracted participants' focused attention more than the emotionally-neutral sentences leading to better encoding of the numerical information within the sentences.

It is important to note here that emotional valence in general may have enhanced associative memory for numerical information, but the negatively-valenced sentences appeared to provide an additional benefit over and above the positively-valenced sentences. This is consistent with some prior research demonstrating a "negativity bias" in memory, in which negative information may receive more processing resources than positive information (Grühn, Smith, & Baltes, 2005) and may be processed in a more detail-oriented manner, while positive or neutral information may be processed in a more schematic manner (Kensinger, 2009). In turn, negative information may be remembered with more associated contextual details than neutral or positive information (Kensinger, 2009; Kensinger et al., 2006). In the current task, negative sentences may have drawn more attention, allowing participants to process that information in a more detail-oriented fashion, leading to better subsequent memory for associated details.

One theory that may partially account for the results of the current study is the arousal-biased competition theory (ABC theory; Mather & Sutherland, 2011), which states that when multiple sources of information are competing for resources, arousal biases resources towards information that is of high priority. Importantly, high priority information can be determined by both bottom-up or top-down influences. That is, stimuli that are perceptually salient or that are relevant for task goals may receive a memory enhancement from emotional arousal during the encoding period. In the context of the current task, the emotionally-salient sentences were likely given high priority due to both of these factors – their attention-capturing nature (i.e., a bottom-up influence), as well as their tendency to be considered more important to remember (i.e., a top-down influence). This may have biased resources towards that information and its associated details, resulting in enhanced memory for the numerical information within the emotionally-valenced sentences. On the other hand, numerical information presented within emotionally-neutral sentences did not receive any arousal-related enhancement and were thus remembered

less accurately. Thus, the materials employed here allowed for a unique measure of subjective importance in the light of emotional salience.

While this theory can somewhat account for the findings of the current study, it was only the case that *negative* high arousal sentences were better remembered than low arousal sentences. ABC theory and other more recent theories of arousal-driven emotional memory (e.g., Clewett & Murty, 2019) would predict that this would also be true for positive valence sentences, which was not the case, even though positive valence sentences were rated as more arousing. This negative-specific enhancement is more in line with a recently proposed valence-based account of emotional memory (Bowen, Kark, & Kensinger, 2018) suggesting that negative features of information may more intensely enhance the encoding of sensory detail and increase the storage strength of that information over time, relative to positive features. Given that negative high arousing sentences were the most accurately remembered in the current study, this finding suggests that some interaction between these two theories may account for the results presented here. That is, within the context of numerical associative memory, arousal-enhanced binding appears to be selective to negative stimuli. Positive stimuli, while better remembered than neutral stimuli overall, do not appear to benefit from increased arousal. As such, the current study provides some evidence to bridge the gap between arousal-based and valence-based theories of emotional memory and suggests that future research should consider the potential interaction between these two accounts.

The paradigm utilized here differed from previous emotional associative memory work in several ways, which led to both an extension of prior findings and some apparent discrepancies. Unlike previous work which has utilized word pairs (e.g., Madan et al., 2012; Naveh-Benjamin et al., 2012) or pictures in locations (e.g., Mather et al., 2006; Nashiro & Mather, 2011) to examine associative emotional memory, the current study found this emotional enhancement

using more naturalistic stimuli, providing a richer context more akin to real-world scenarios than other previous lab-based studies. The findings of this study suggest that older adults may, for example, when reading or listening to news headlines more accurately remember negative and highly arousing news stories over positive or neutral news stories. Future work can explore emotional binding in the context of non-numerical memory, by presenting sentences of varying valence and arousal from different sources. It is well established that older adults have poorer source memory than younger adults (Schacter, Kaszniak, Kihlstrom, & Valdiserri, 1991). Consistent with prior work showing that older adults' source memory impairments may be eliminated for emotional information (May et al., 2005), our results predict that older adults may more accurately remember the source of negative and positive information over neutral information in other realistic contexts, which warrants further investigation.

Further, another critical difference between the current study and previous work relates to the manner of testing. In the current study, a recall test was used in which participants had to produce the relevant number from memory when shown each sentence. This type of test has been shown to be more cognitively demanding than recognition testing where participants must recognize which association was previously presented from a number of alternatives, as recall may depend solely on conscious recollection of information, as opposed to recollection and feelings of familiarity (Jacoby, Toth, & Yonelinas, 1993; Mandler, 1980). A dearth of prior work has demonstrated that older adults may exhibit disproportionate deficits in recall relative to recognition (Craik, & McDowd, 1987; Danckert & Craik, 2013; Jennings & Jacoby, 1997), perhaps related to older adults' reliance on gist-based processing and memory (Brainerd & Reyna, 2001; Gallo et al., 2019; Koutstaal, 2006; Reder et al., 1986; for a recent in-depth meta-analysis on older adults' recognition memory, see Fraundorf, Hourihan, Peters, & Benjamin, 2019). An amended version of the current study could present participants with sentences

containing numbers varying in emotional valence and examine associative memory between younger and older adults using recognition testing (e.g., a 5-alternative-forced-choice test). In this altered paradigm, older adults may experience a smaller decrement in performance relative to younger adults and age-related deficits in numerical associative memory may be attenuated or eliminated for emotional (and particularly arousing negative) information.

Finally, a limitation of the current study relates to the manner in which participants' memory for the numerical information was examined. As the current study did not examine individual component memory, but rather the association between a numerical value and context, we cannot conclusively determine whether emotional emotion-enhanced associative memory directly, or indirectly by enhancing individual component memory (which may have led to better memory for associations). What is clear in the current study is that emotion-enhanced binding is present for associated numerical information for both younger and older adults. Future studies should examine both individual component memory for the numerical information and contexts individually, as well as the association in order to determine the mechanism underlying the effects of emotional valence on memory. In sum, the current study demonstrates that emotion-enhanced binding in the context of naturalistic materials is consistent between younger and older adults and that specific and arbitrary numerical information is better remembered when encountered in an emotional context.

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Table 1

Recall and Subjective Importance and Difficulty Ratings as a Function of Sentence Valence

Emotional Valence	Sentence	Answer	Digit Length	Recall Accuracy	Importance Rating	Difficulty Rating
Negative	The man died while climbing a mountain at an altitude of [number] feet.	17092	5	.02	4.21	5.85
	[number] people were infected with Zika virus at the Olympics.	103546	6	.06	4.87	5.74
	Doses of the drug greater than [number] milligrams will result in vomiting.	350	3	.40	5.48	3.65
	[number]% of the city was destroyed in the fire.	21	2	.53	4.90	3.69
	A recent news story reported that a woman was held in slavery for [number] years.	28	2	.53	5.05	3.53
	The ages of the kidnapped children were [number] and [number].	6,11	3	.67	5.21	3.13
	The bank robber was [number] feet [number] inches tall, and had [number] previous felony convictions.	6,4,7	3	.69	5.06	3.35
	Each year, [number] in [number] neurosurgeons face a malpractice claim.	1,5	2	.74	5.32	2.65
Neutral	The fast food restaurant served [number] people.	8456	4	.03	3.84	6.15
	The building's new wing was [number] square feet.	14500	5	.10	4.26	5.27
	The shipping freighter carried [number] pounds of cargo.	78000	5	.10	4.23	5.00
	The cost of the new art museum in New York will be $[number] million.	780	3	.11	4.26	4.85
	The flight leaves at [number] pm.	8:47	3	.24	5.15	4.61
	There were [number] people at the town hall meeting.	48	2	.29	4.37	4.58
	Over the summer, the price of a bag of oranges was $[number].	3.47	3	.37	4.42	3.94
	The restaurant is located on North [number]st street.	31	2	.68	5.08	2.95
Positive	The non-profit organization fed [number] families during the holidays.	1189	4	.05	4.35	5.50
	The man donated his entire $[number] savings to the charity.	475000	6	.18	4.42	4.71
	This year, crime was reduced by [number]%.	52	2	.31	4.89	4.39
	The woman just won $[number] million in the Oregon lottery.	5.1	2	.34	4.48	4.27
	The ice cream truck is giving away free popsicles between [number] and [number].	5:30, 7:15	6	.41	4.53	3.73
	Grandma's surprise birthday party is at [number] pm.	3:30	3	.44	5.05	3.53
	The couple just celebrated their [number]th anniversary.	65	2	.58	4.84	3.08
	After years of dieting and exercise, the man finally reached his goal of losing [number] pounds.	110	3	.71	4.65	3.00

Note. Importance ratings were provided on a scale from 1 (*not at all important to remember*) to 7 (*very important to remember*) and difficulty ratings on a scale from 1 (*very easy to remember*) to 7 (*very difficult to remember*).

Table 2

MTurk Workers Ratings as a Function of Sentence Valence

Emotional Valence	Sentence	Valence Rating	Arousal Rating	Importance Rating	Difficulty Rating
Negative	A recent news story reported that a woman was held in slavery for 28 years.	1.99	4.24	4.27	3.23
	The ages of the kidnapped children were 6 and 11.	2.00	4.14	4.95	2.96
	21% of the city was destroyed in the fire.	2.26	4.22	4.47	3.31
	103546 people were infected with Zita virus at the Olympics.	2.32	4.03	4.48	5.25
	The man died while climbing a mountain at an altitude of 17092 feet.	2.36	3.41	2.97	5.16
	The bank robber was 6 feet 4 inches tall and had 7 previous felony convictions.	2.57	3.61	4.08	4.24
	Each year, 1 in 5 neurosurgeons face a malpractice claim.	2.78	3.54	4.08	3.40
	Doses of the drug greater than 350 milligrams will result in vomiting.	2.86	3.48	4.59	3.72
Neutral	Over the summer, the price of a bag of oranges was $3.47.	3.90	2.64	2.50	4.41
	The cost of the new art museum in New York will be $780 million.	4.04	3.36	2.69	4.50
	The restaurant is located on North 31st street.	4.06	2.53	2.74	4.45
	The building's new wing was 14,500 square feet.	4.08	2.76	2.29	5.18
	The shipping freighter carried 78,000 pounds of cargo.	4.10	2.54	2.28	4.82
	There were 48 people at the town hall meeting.	4.10	2.55	2.60	4.19
	The fastfood restaurant served 8,456 people.	4.15	2.96	2.03	5.35
	The flight leaves at 8:47 pm.	4.24	3.42	3.88	3.68
Positive	The woman just won $5.1 million in the Oregon lottery.	5.22	4.36	2.64	3.92
	After years of dieting and exercise, the man finally reached his goal of losing 110 pounds.	5.34	3.95	2.86	3.73
	Grandma's surprise birthday party is at 3:30 pm.	5.40	4.49	4.48	2.94
	This year, crime was reduced by 52%.	5.46	4.06	4.42	3.34
	The ice cream truck is giving away free popsicles between 5:30 and 7:15.	5.47	4.48	3.88	3.56
	The couple just celebrated their 65th anniversary.	5.53	3.85	2.82	3.46
	The non-profit organization fed 1,189 families during the holidays.	5.60	3.99	3.40	4.73
	The man donated his entire $475,000 savings to the charity.	5.67	4.24	3.67	3.95

Note. Valence ratings were provided on a scale from 1 (*very negative*) to 7 (*very positive*) and arousal ratings on a scale from 1 (*very unarousing*) to 7 (*very arousing*). Importance and difficulty ratings were provided on the same scale as in Table 1.
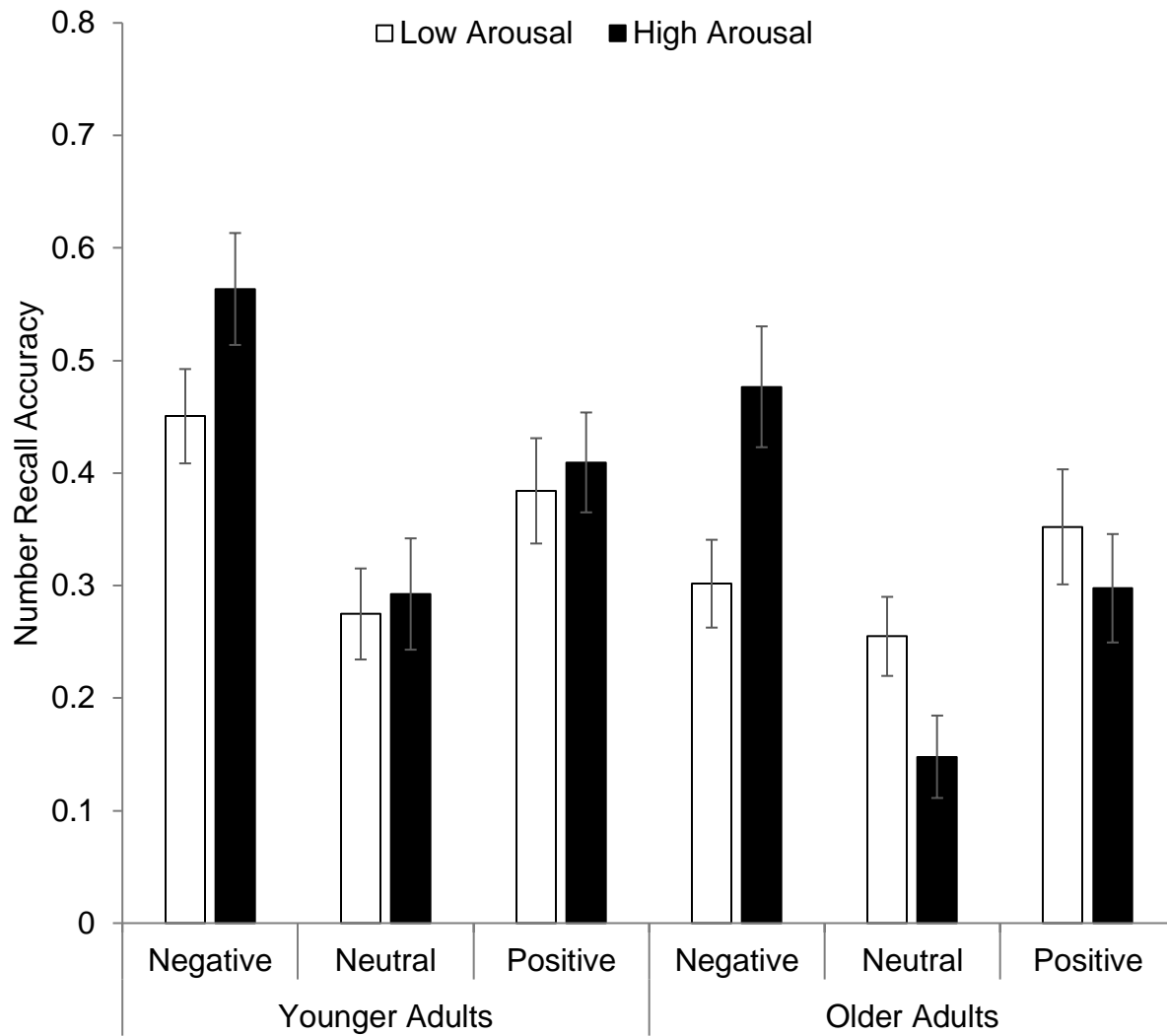
Figure 1. Number recall accuracy (the proportion of sentences in which all numerical information was correctly recalled) as a function of age group, valence, and arousal. Responses were only considered correct if the exact numerical values were entered. Error bars represent ±1 standard error of the mean.
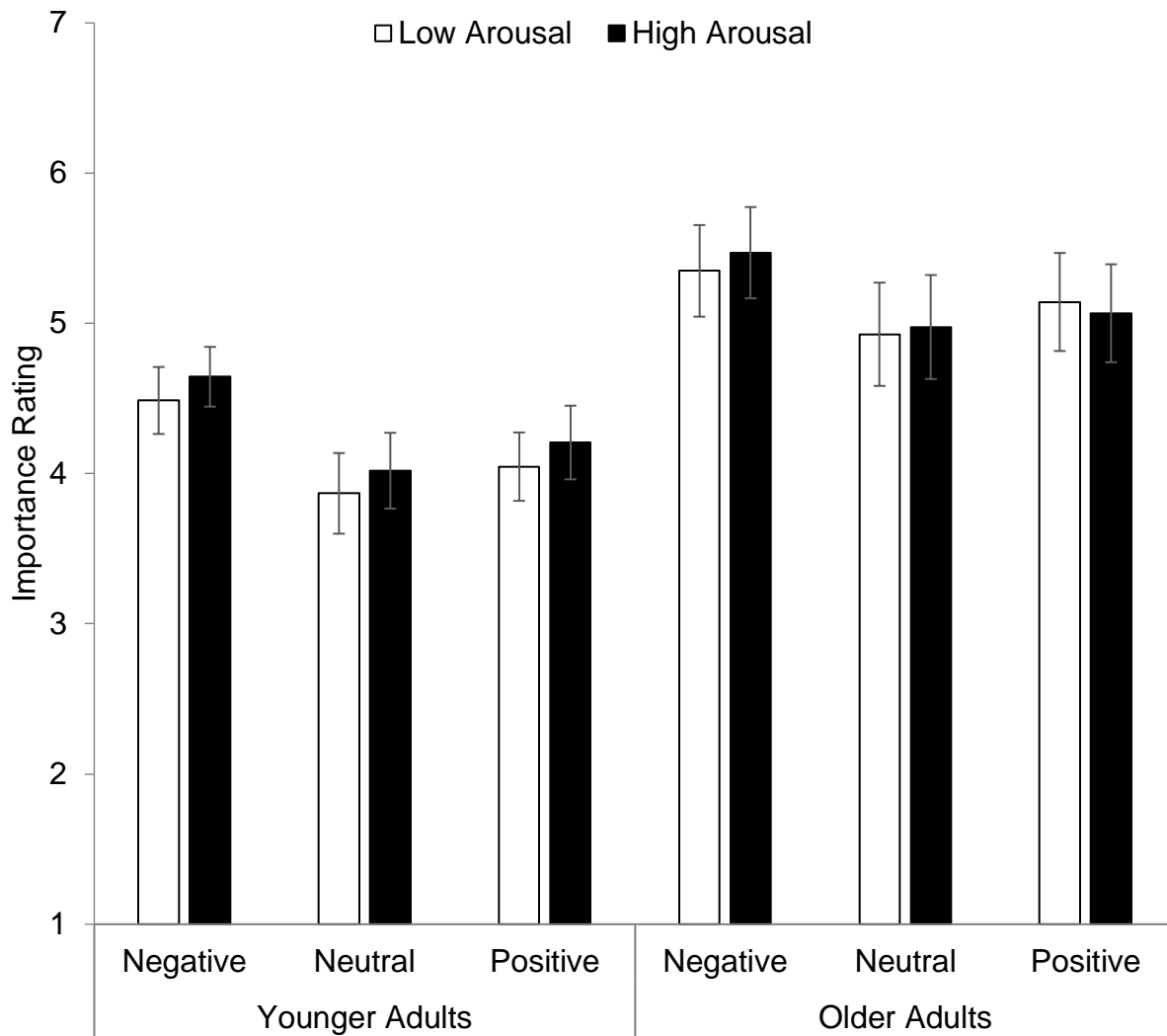
Figure 2. Participants' subjective ratings of sentence importance (left panel) as a function of age group, valence, and arousal. Importance ratings were provided on a scale from 1 (*not at all important to remember*) to 7 (*very important to remember*). Error bars represent ±1 standard error of the mean.
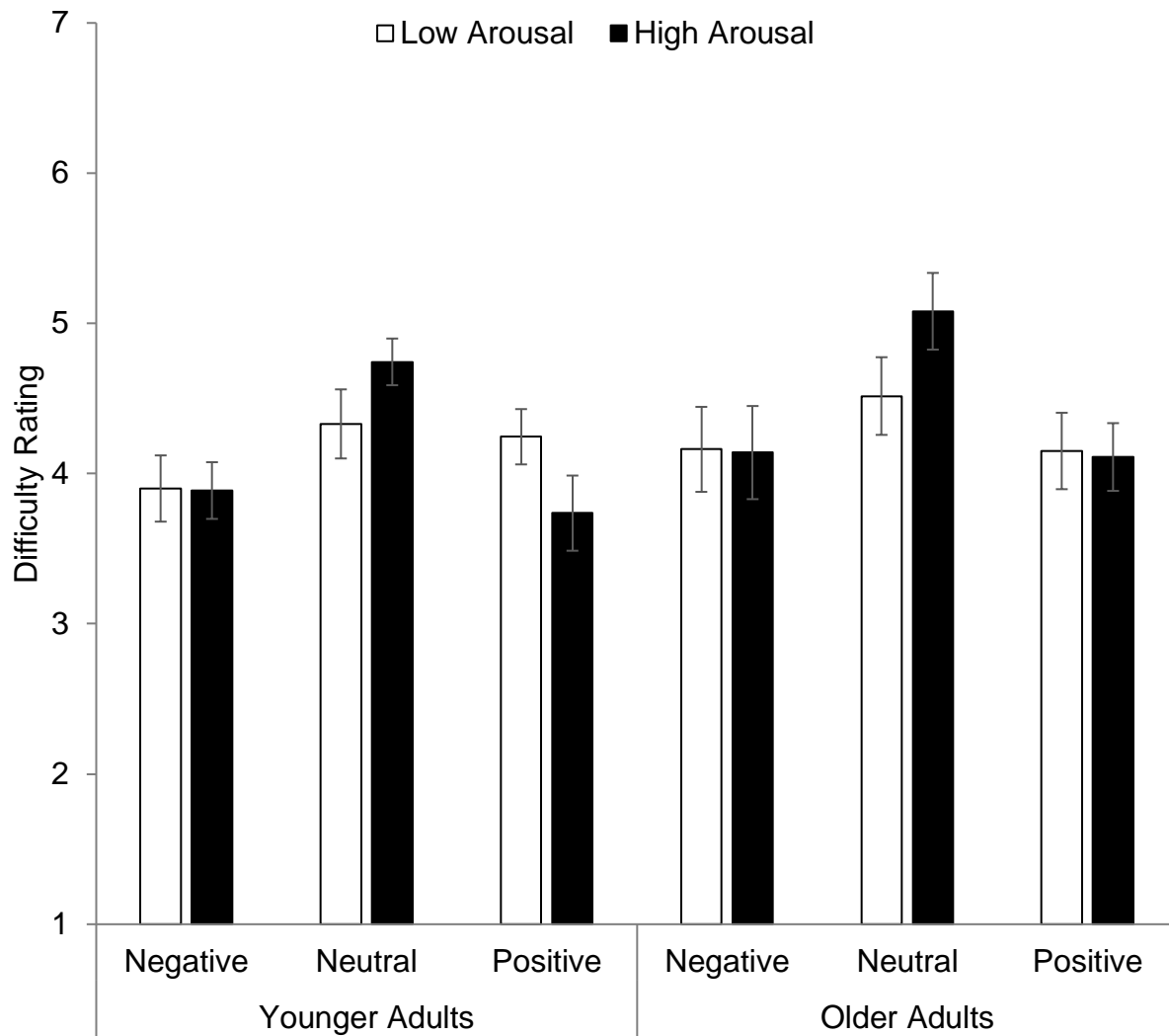
Figure 3. Participants' subjective ratings of sentence difficulty as a function of age group,

valence, and arousal. Difficulty ratings were provided on a scale from 1 (*not at all difficult to*

remember) to 7 (*very difficult to remember*). Error bars represent ±1 standard error of the mean.