Journals of Gerontology: Psychological Sciences
cite as: *J Gerontol B Psychol Sci Soc Sci*, 2021, Vol. 76, No. 10, 2013–2022
https://doi.org/10.1093/geronb/gbab124
Advance Access publication July 07, 2021

Research Article

Age, Sex, and Inhibitory Control: Identifying a Specific Impairment in Memorial, But Not Perceptual, Inhibition in Older Women

Alexander L. M. Siegel, PhD and Teal S. Eich, PhD*,

The Davis School of Gerontology, University of Southern California, Los Angeles, California, USA.

*Address correspondence to: Teal S. Eich, PhD, Davis School of Gerontology, University of Southern California, 5715 McClintock Avenue, Los Angeles, CA 90089, USA. E-mail: teich@usc.edu

Received: February 2, 2021; Editorial Decision Date: June 23, 2021

Decision Editor: Angela Gutchess, PhD

Abstract

Objectives: Declines in the ability to inhibit information, and the consequences to memory of unsuccessful inhibition, have been frequently reported to increase with age. However, few studies have investigated whether sex moderates such effects. Here, we examined whether inhibitory ability may vary as a function of age and sex, and the interaction between these two factors.
Method: 202 older (mean age = 69.40 years) and younger (mean age =30.59 years) participants who had equivalent educational attainment and self-reported health completed 2 tasks that varied only in the time point at which inhibition should occur: either prior to, or after, encoding.
Results: While we did not find evidence for age or sex differences in inhibitory processes when information needed to be inhibited prior to encoding, when encoded information being actively held in working memory needed to be suppressed, we found that older women were particularly impaired relative to both younger women and men of either age group.
Discussion: These results provide further support for the presence of memorial inhibitory deficits in older age, but add nuance by implicating biological sex as an important mediator in this relationship, with it more difficult for older women to inhibit what was once relevant in memory.

Keywords: Aging, Control, Inhibition, Sex, Working memory

The role that biological sex plays in processes ranging from health and longevity to cognitive functioning has been the source of significant inquiry (see Miller & Halpern, 2014, for a review). Much research, for example, has investigated episodic long-term memory ability as a function of biological sex. While in general episodic memory ability is greater in women (Maitland et al., 2004), the direction of the sex-related episodic memory advantage seems to depend on the type of to-be-remembered materials: women have superior memory for verbal materials while men have superior memory for visuospatial materials (Herlitz & Rehnman, 2008). Whereas some work has found sex-related differences in working memory abilities, most notably a male advantage in spatial, but not verbal, working memory (Voyer et al., 2017), this advantage has been found to be fairly small (Saylik et al., 2018), nonexistent (Robert & Savoie, 2006), or, in some cases, reversed (Duff & Hampson, 2001).

The effects of sex on the ability to inhibit information, and the consequences to memory of successful or unsuccessful inhibition, are relatively understudied. Yet, inhibitory control represents a crucial aspect of daily functioning, as we are constantly inundated with information that we are forced to select for (or against) by virtue of the limited nature of available cognitive resources. It is well established that inhibitory control processes worsen with age (Sylvain-Roy et al., 2015), and indeed, such failures of inhibitory abilities may underlie many age-related cognitive deficits according to Hasher and colleagues' (2007) Inhibitory Deficit Theory. It has been posited from an evolutionary perspective that women may be more effective at inhibition than men due to greater pressures to prevent maladaptive emotional, social, and sexual behaviors (Hosseini-Kamkar & Morton, 2014). While these effects are evident in behavioral and social inhibition, the extent to which this benefit permeates down to cognitive processes has been called into question based on mixed findings of sex on various cognitive inhibition tasks (Bjorklund & Kipp, 1996). Rather than domain-general age deficits in inhibitory processing, evidence suggests that inhibition is not a unitary construct (Friedman & Miyake, 2004), and the ability to inhibit information may depend on when in the memory-processing stream inhibition takes place. Information can be ignored during encoding (i.e., perceptual inhibition) or after encoding has taken place during retrieval (i.e., memorial inhibition). Failures in each of these types of inhibition may lead to memory errors (Healey et al., 2013). For example, older adults have been shown to be impaired in perceptual inhibition across a variety of different experimental paradigms (Hasher et al., 1991; Lustig & Hasher, 2001; Rozek et al., 2012). Importantly, this deficit in selective attention and perceptual inhibition may only occur at very early stages of processing with age-related differences resolving relatively quickly during the encoding process (i.e., 550 ms after the start of encoding) in some studies (Gazzaley et al., 2008; Wnuczko et al., 2012). In terms of potential sex differences in early inhibition, some previous work has found differences between females and males in selective attention, a process which supports inhibition at the perceptual level by guiding attention towards task-relevant and away from task-irrelevant stimuli. On a flanker task, women were shown to be more distracted by incongruent stimuli while men were more effective in ignoring these irrelevant distractors (Stoet, 2010). In each of these studies, however, only younger adults were tested and, in general, there is little work exploring how age and sex may interact to affect perceptual inhibition.

With regards to inhibiting already consolidated information or information that is actively being maintained in working memory, age differences have also been reported. In directed forgetting paradigms in which some information is designated to be remembered and some to be forgotten (or inhibited) after it has already been encoded, a number of groups have reported that older adults produce more errors by remembering to-be-forgotten words despite their "forget" designation (see Titz & Verhaeghen, 2010). There is also documented evidence of older adults' difficulties in suppressing information already in memory on a think/no-think paradigm (Anderson et al., 2011), when required to suppress a competitor for an orthographically similar word when solving word fragments (e.g., suppressing ANALOGY in favor of ALLERGY when solving for A_L__GY; Healey et al., 2013), and on a previously published study using the same Sternberg-like working memory task used in the current study but in a smaller sample (Eich et al., 2018). To date, however, limited research has investigated the effect of sex on memorial inhibition. One directed forgetting study found negligible differences between men and women on the ability to inhibit to-be-forgotten items (Yang et al., 2013). Another found that postmenopausal women exhibited reduced forgetting ability relative to younger women and men (Kerschbaum et al., 2017). Thus, as it currently stands, research into potential sex differences in memorial suppression remains scant.

While empirical support is limited, there are theoretical reasons to suppose that age and sex may interact to affect inhibitory ability. There is evidence of altered cognitive functioning in females following menopause (Morgan et al., 2018). Estradiol, a major sex hormone that decreases in prevalence during menopause (Shanmugan & Epperson, 2014), has been shown to influence working memory and executive functioning by augmenting hippocampal and prefrontal function (Hampson, 2018), the latter of which is a region that is typically associated with inhibition (Eich et al., 2017; Nee & Jonides, 2008). It stands to reason, then, that postmenopausal females (i.e., older adult women) may experience accelerated declines in inhibitory ability relative to older males and younger females, given the reduced beneficial influence of estrogens on the prefrontal cortex that occurs with advancing age and transition to the postreproductive period of life (Shanmugan & Epperson, 2014). While the aim of the current study was not to definitively implicate the role of estrogens in the inhibitory ability of older women, it represents one potential mechanism that may underlie differential changes in inhibition between older females and males, and motivated our investigation of how aging may influence adults' inhibitory ability differently between sexes.

The primary goal of the current study, then, was to examine how the ability to inhibit information at different time points (i.e., prior to and after encoding) may vary as a function of age and sex, and the interaction between these two factors. Younger and older men and women completed two tasks designed to dissociate differences in perceptual and memorial inhibition based on when in the memory-processing stream information needs to be inhibited (Nee & Jonides, 2008). These tasks have been used to investigate these processes across a number of participant populations, including schizophrenia (Smith et al., 2011), major depression (Joormann et al., 2010), and obsessive compulsive disorder (Ahmari et al., 2014). Both tasks were modeled after the classic letter Sternberg task, in which a set of letters is presented, and then memory for an item that either was or was not in the set is probed after a delay. Thus, like the Sternberg, these tasks provide an index of general working memory ability in participants.

However, the tasks diverge from the Sternberg in a critical way: Either prior to the memory set or following it, participants were instructed to maintain only a subset of the items. That is, in the Suppress task, like in the Sternberg, participants first had to maintain a word set in working memory. However, unlike the Sternberg, participants were then told to maintain only half of the words in memory until a recognition probe was given. In the Ignore task, participants were first told which half of the set they should attend to (based on the color of the words), and then were given the word set, followed by the recognition probe. In the Suppress task, then, all words in had to be maintained in working memory until the instruction cue was given, at which point the noncued words could be dropped. In the Ignore task, the noncued items could be perceptually dropped before encoding. The Suppress task thus fosters inhibition of information already in memory, whereas the Ignore task fosters inhibition of items prior to encoding. The inclusion of this cue allows us to assess, through recognition tests that probe memory for an item that should have been maintained (valid), an item that should have been dropped (lure), or an item that was not part of the word set at all (control), both inhibitory ability as well as working memory.

As recently discussed by Bessette and colleagues (2020), inhibition is a complex construct that is often cofounded by and conflated with other similar processes. According to these authors, "The process of inhibition involves increasing and decreasing levels of interference resolution (IR) via experimental manipulations of distractors, timing, instruction sets, and individual differences in inherent proclivity for responding. Successful inhibition, or inhibitory control (IC), is the ability to apply the correct response or inhibit unwanted responses" (p. 478). In our task, a failure to inhibit either perceptually, or memorially, should lead to different demands on IR processes, which we operationalize as the difference score between the two different types of probe items that require a negative response: control items and lure items. The Lure–Control Inhibition Index quantifies the cost of having to draw upon IR processes due to a failure in inhibitory processes.

In the Suppress task, lure items that have been dropped from working memory should be equivalent to control items in memory: they should not be familiar, and thus will not require IR processes to facilitate a correct response. Lure items that were not appropriately dropped from working memory, on the other hand, will cause interference at the time of the probe, necessitating IR processes, which will increase errors and reaction time (RT) for correct responses. For the Suppress task, then, a Lure–Control Inhibition Index score close to zero indicates that a participant rejected lure items just as quickly as control items, suggesting a low cost associated with lures and good inhibition, while a positive Inhibition Index score indicates that a participant took longer to respond to lure stimuli relative to control stimuli, presumably because they had to engage IR processes, suggesting a higher cost and poorer inhibition. As a failure to bind the words and colors may also explain an increased Inhibition Index, the valid trials serve a critical function in the task design, providing a baseline for this ability in addition to overall baseline working memory ability. That is, in the case of the Suppress task, from the participants' perspective, all words and colors must be bound before inhibition can take place, as the cue telling participants which color words to retain comes only after the word set has been presented. A failure to either bind the colors and words, or to maintain information in working memory, would thus be apparent in performance on the valid trials.

For the Ignore task, on the other hand, a larger positive difference is thought to be indicative of intact perceptual inhibition. This is based upon the supposition that successfully perceptually inhibited items need to first be released from inhibition before they can be available to conscious awareness for deliberation at the time of the probe. While perhaps counterintuitive at first glance, the direction of this effect (which is opposite to that of the Suppress task) is based upon three sources of work: first, Tipper (2001) found, using a simple match-to-sample task, that younger adults exhibited accuracy and RT costs when an item that had served as a distractor on a previous trial became a target on a subsequent trial, whereas older adults did not evidence this effect. Tipper argued that the increased RT and errors for younger adults stemmed from the fact that these items that were distractors were inhibited, and when they became targets on the subsequent trial, they needed to be released from this inhibition. The lack of the so-called "negative priming" effect in older adults stemmed from their failure to perceptually inhibit the irrelevant target on the previous trial, which lead to facilitated performance on the later trial. Second, Eich and colleagues (2018) found, using the Ignore and Suppress tasks in a different (and smaller) sample of participants, that older adults had lower Inhibition Indexes relative to younger adults for the Ignore task, but higher Inhibition Indexes on the Suppress task. Finally, we also found, in a small sample of older adults, that the Inhibition Index of the Ignore task correlated with cortical thickness in the right superior parietal lobule, such that participants with higher Inhibition Index scores had thicker cortices in this region (Eich et al., 2017). This brain region has previously been shown in a functional neuroimaging study of younger adults to be involved in the inhibition of perceptual information (Nee & Jonides, 2008). Thus, for the Ignore task, we predicted that if age or sex imparted impairments in the ability to inhibit items perceptually, that these items would not need to be released from inhibition to be available to conscious awareness, which would result in a smaller Lure–Control Inhibition Index score.

We examined differences in the ability to inhibit information at these time points as a function of participants' age and sex to add more clarity to the literature on inhibitory control and aging, and to determine whether sex plays a significant role in cognitive inhibition at either one or both of these time points. While participants completed a battery of other tasks thought to tap different aspects of inhibition, only data from the Ignore and Suppress tasks were considered here because these two tasks were experimentally matched across everything except for the time point at which the inhibition instruction occurred (before or after the word set), and the instruction cue itself (attend RED/BLUE vs remember RED/BLUE). The other two memory inhibition tasks not analyzed here were a Directed Forgetting task and a Retrieval Induced Forgetting task. In these tasks, a distractor phase followed encoding, and thus memory on these tasks was probed after a substantially longer delay. In the Ignore and Suppress tasks, on the other hand, memory was probed on each trial, shortly after encoding, and thus the words were still presumably being rehearsed actively in working memory. The other three inhibition tasks were perceptual in nature.

Similar to prior work utilizing these paradigms with older adults (Eich et al., 2017, 2018), we predicted that age differences in inhibitory ability would be larger when irrelevant information was already encoded (i.e., in the Suppress task) relative to when it had not yet been encoded (i.e., in the Ignore task). Our predictions with regards to how sex would influence inhibition individually or in an interaction with age were less definitive due to the dearth of prior work in this area. Evidence from selective attention paradigms like the flanker task implicate a potential deficit in perceptual inhibition for females relative to males in younger adult samples (Stoet, 2010); however, if this deficit was indeed present in the Ignore task, we did not expect it to differ as a function of age group, as prior work has found only small age differences in this task (Eich et al., 2018). Where we predicted age and sex may interact to affect inhibitory ability was in the Suppress task, in which documented impairments exist in suppressing information already encoded into working memory for both older adults relative to younger adults (Titz & Verhaeghen, 2010) and, with limited evidence, for females relative to males (Kerschbaum et al., 2017). As such, these two factors (older age and female sex) may produce an additive effect on the ability to suppress already-encoded irrelevant information and lead to disproportionate deficits on the Suppress task relative to older males and/or younger females. On the other hand, the lack of biological sex differences on memorial inhibition found in other contexts (Yang et al., 2013) would suggest that age-related impairments on the Suppress task found in prior work (Eich et al., 2017, 2018) should be present in older adults of both sexes to the same extent. The current study aimed to tease apart these differing predictions and provide more conclusive evidence towards establishing the relationship between age, sex, and in control.

Method

Participants

Two hundred and two community-dwelling English-speaking adults completed the Ignore and Suppress tasks

Table 1. Mean (*SD*) Accuracy (proportion correct) and Reaction Times (milliseconds) for Correct Trials for the Ignore and Suppress Tasks

		Ignore task				Suppress task			
		Younger adults		Older adults		Younger adults		Older adults	
		Male	Female	Male	Female	Male	Female	Male	Female
Valid trials	Accuracy	0.92 (0.09)	0.94 (0.11)	0.93 (0.17)	0.98 (0.03)	0.92 (0.10)	0.90 (0.14)	0.94 (0.08)	0.93 (0.08)
	RT	1263 (413)	1267 (544)	1306 (393)	1414 (353)	1313 (501)	1308 (462)	1587 (354)	1624 (420)
Lure trials	Accuracy	0.94 (0.10)	0.94 (0.08)	0.96 (0.07)	0.97 (0.05)	0.88 (0.13)	0.87 (0.17)	0.87 (0.19)	0.86 (0.16)
	RT	1306 (470)	1353 (569)	1315 (392)	1452 (376)	1585 (537)	1553 (610)	1846 (445)	2022 (516)
Control trials	Accuracy	0.99 (0.03)	0.99 (0.03)	1.00 (0.03)	1.00 (0.01)	0.95 (0.12)	0.95 (0.10)	0.91 (0.16)	0.94 (0.13)
	RT	1275 (428)	1279 (520)	1271 (437)	1392 (397)	1291 (376)	1318 (468)	1590 (389)	1601 (429)

Note: RT = reaction time.

as part of a larger study aimed at exploring changes to inhibition in aging (the Study Of the Factor Structure of Inhibition in Aging ['SOFIA'] study). The sample included 85 younger adults who ranged in age from 19 to 40 years (M = 30.59, SD = 5.57, 55 females, 30 males) and 117 older adults who ranged in age from 60 to 84 years (M = 69.40, SD = 5.86, 65 females, 52 males). A post-hoc sensitivity analysis in G*Power to identify the minimal detectable effect in the available sample. This analysis indicated that with the observed sample of 202 participants, the minimal detectable effect size for a within–between interaction was Cohen's f = .12 (η^2 = .01), indicating that the sample was capable of detecting a "small" effect (Cohen, 1988).

The majority of participants in the SOFIA study (81%) had previously taken part in one of several large, ongoing studies at Columbia University (CU): the Cognitive Reserve Study (CR) and the Reference Ability Neural Networks Study (RANN). Exclusion criteria for the CR/RANN studies, described in detail elsewhere (see Stern et al., 2014), included hearing impairment, objective cognitive or functional impairment, diagnosis of a neurologic or psychiatric disorder, or serious memory complaint at the time of recruitment. Additionally, all older participants were screened for dementia using the Mattis Dementia Rating Scale and were eligible to participate only if their score was 135 or better. The remaining 19% of participants, all of whom were younger adults, were recruited to the study via study advertisements placed on and around the CU Medical Center and CU Morningside campuses. Participants were compensated $40 for their participation in each testing session. Informed consent, as approved by the CU Institutional Review Board, was obtained for all participants.

Materials and Procedure

The current study was conducted entirely online. The materials and procedure were similar to those used in Eich and colleagues (2017, 2018). Participants completed two tasks, the Ignore task and the Suppress task, across two separate testing sessions that included several other cognitive tasks, counterbalanced across participants. All tasks were administered using the Inquisit software platform (www.millisecond.com). The word stimuli for both tasks were separate sets of 80 four-letter nouns (e.g., "POOL," "RING").

In the Ignore task, participants were first presented with a cue for 1,500 ms which instructed them to attend to either the red or blue words. After a 1,000-ms delay, participants were presented with four words, two in red and two in blue, in a 2 × 2 grid configuration for 5,000 ms. Following a 3,000-ms delay, participants were given a test probe and asked to make a judgment about whether the test word was a word that should have been attended. Responses were made by pressing either the "Y" key on the keyboard (for "Yes," to indicate a positive response) or the "N" key (for "No") to indicate a negative response. The test probe remained on screen for 10,000 ms, or until a response was made. Of the test probes, 40% were "Valid" trials in which the test word was one of the words participants were told to attend to, requiring a positive response, 30% were "Lure" trials in which the test word was one of the words that participants should not have attended to, requiring a negative response, and 30% were "Control" trials in which the test word was not present in the array, requiring a negative response. The Suppress task similar to the Ignore task except in the position of the word set relative to the instruction cue: the word array appeared first for 5,000 ms, followed by a 1,000 fixation, and then the cue, presented for 1,500 ms, which in this task instructed participants to remember either the red or the blue words. This word set was followed by a 1,000 ms delay, and then the test probe.

Participants completed four blocks of 25 trials of both the Ignore and Suppress tasks. Participants had to achieve 60% accuracy on each of two practice blocks with feedback before they could begin the experiment. Feedback was not provided on experimental trials.

Statistical Analysis

Sample characteristics were examined using Student's t tests. General linear models were used to examine overall task performance for both the mean RT (i.e., the time in milliseconds participants took to provide a response when presented with the test probe for correct trials only) and accuracy as a function of inhibition type (Ignore task, Suppress task), trial type (valid, lure, control), age group (younger adults, older adults), and sex (female, male). Then, we analyzed our main measure of inhibition, the Lure–Control Inhibition Index using general linear models that considered inhibition type (Ignore task, Suppress task), age group (younger adults, older adults), and sex (female, male). In case of sphericity violations, Greenhouse–Geisser corrections were used. Follow-up comparisons were adjusted with Bonferroni corrections and when equal variance assumptions were violated, Welch's unequal variances t tests were used. In addition to traditional frequentist statistics, we also conducted Bayes factor (BF) analyses in an effort to address the potential limitations of frequentist statistics by allowing for an assessment of the strength of evidence for the alternative hypothesis relative to the null hypothesis (for a review of the benefits of the Bayesian statistical approach in psychology, see Wagenmakers et al., 2017). The Bayesian analyses of variance (ANOVAs) were conducted in JASP (JASP Team, 2020) using default priors.

Results

Sample Characteristics

Education level did not differ between age groups, $t(200)$ = 0.22, p = .83, d = .03, and sex, $t(200)$ = 1.34,

p = .18, d = .19. Self-reported health also did not differ between age groups, $t(186) = 1.39$, p = .17, d = .21, and sex, $t(186) = 0.23$, p = .82, d = .03. National Adult Reading Test (NART) and Wechsler Test of Adult Reading (WTAR) scores were available only for participants who had completed the RANN/CR studies (NART: 114 older adults, 54 younger adults; WTAR: 111 older adults, 48 younger adults). We conducted 2 (Age group) × 2 (Sex) between-subject ANOVAs on each of these measures and the only significant effect was a main effect of age on NART scores, $F(1, 164) = 6.70$, p = .001, η^2 = .04, with older adults (M = 119, SD = 8) outperforming younger adults (M = 115, SD = 7), all other ps >.19.

Overall Task Performance

Mean accuracy rates and RTs are presented in Table 1. Complete results from all models on accuracy and mean RT are presented in Supplementary Material. In brief, both younger and older participants had very high performance, averaging fewer than 7% errors (93% and 94% accuracy, respectively) across the experiment.

Inhibition Index

Because accuracy was near ceiling and was equivalent across both sex and age groups, the analyses presented here focus on RTs on correct trials as the primary dependent variable of interest. For our primary measure of inhibition, we analyzed the Inhibition Index for RTs, calculated as the difference scores in average RT between the two kinds of negative probes (lure and control trials). As illustrated in Figure 1, a mixed-subject ANOVA of the RT Inhibition Index as a function of inhibition type, age group, and sex found a main effect of inhibition type, $F(1, 176) = 104.10$, $p < .001$, $\eta^2 = .36$, with a higher overall Inhibition Index on the Suppress task relative to the Ignore task. There was also an Age group × Sex interaction, $F(1, 176) = 4.94$, p = .03, η^2 = .03, which was qualified by an Inhibition type × Age group × Sex interaction, $F(1, 176) = 9.84$, $p = .002$, $\eta^2 = .02$. To break down this interaction, we conducted between-subject ANOVAs examining the effects of age group and sex within each inhibition type. In the Ignore task, there were no main effects of age group or sex and no interaction between the two variables, ps > .19. However, in the Suppress task, while there were also no main effects, ps > .10, there was a significant interaction, $F(1, 183) = 6.25$, $p = .01$, $\eta^2 = .03$. For younger adults, there was no significant difference between males (M = 294.50, SD = 339.40) and females (M = 235.50, SD = 312.00), $t(74) = 0.76$, $p_{adj} = .90$, but for older adults, females (M =421.10, SD = 285.40) had a significantly higher RT Inhibition Index than males (M = 255.40, SD = 247.60), $t(109) = 3.22$, $p_{adj} = .004$. When comparing within sexes, there was no significant difference between younger males (M = 294.51, SD = 339.35) and older males (M = 255.38, SD = 247.63), $t(73) = 0.57$, p_{adj} > .99, but younger females (M = 235.51, SD = 312.01) had a significantly lower average RT Inhibition Index than older females (M = 421.14, SD = 285.37), $t(110) = 3.28$, p_{adj} = .002. The omnibus ANOVA did not reveal any other significant effects, ps > .08. These results suggest that, in terms of RTs, older women were particularly impaired at inhibiting lures in the Suppress task, as revealed by a higher Inhibition Index relative to older men and younger women.

We also conducted the same 2 (Inhibition type: Ignore task, Suppress task) × 2 (Age group: younger adults, older adults) × 2 (Sex: female, male) mixed-subject ANOVA on the Inhibition Index using a Bayesian approach. The model with the highest likelihood included the main effects of inhibition type, age, and sex, the Inhibition type × Age, Inhibition type × Sex, and Age × Sex two-way interactions, and the Task type × Age × Sex three-way interaction, $BF_{10} = 1.05 \times 10^{22}$, providing "extremely strong" evidence for this model relative to the null model. The model with the second highest likelihood was the same model without the Inhibition type × Sex two-way interaction or the Inhibition type × Age × Sex three-way interaction, $BF_{10} = 1.25 \times 10^{21}$. Comparing the relative likelihoods provides "moderate" evidence for the best fitting model over the second-best model ($1.05 \times 10^{22}/1.25 \times 10^{21} = 8.46$), and thus moderate evidence for the inclusion of the Inhibition type × Sex term and the Inhibition type × Age × Sex in the best alternative model.

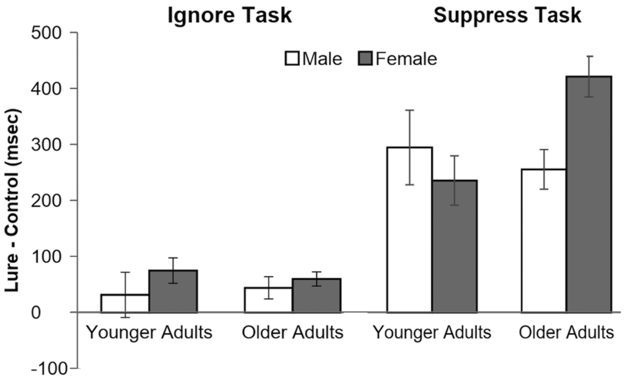

Figure 1. Younger and older men and women's mean Inhibition Index scores (mean lure RT – control RT) for correct trials on the Ignore task (left panel) and the Suppress task (right panel). Error bars represent ±1 SEM. RT = reaction time.

Discussion

Deficits in the ability to inhibit information contribute to impairments in attentional processes and working memory ability in cognitively healthy aging (Hasher et al., 2007; McDowd, 1997). More recent research has implicated sex differences in selective attention (e.g., Stoet, 2017), with results generally indicating that women are more influenced by task/goal-irrelevant information than are men. In the current study, we examined whether these sex differences would persist when inhibition occurred farther down the memory-processing stream (i.e., after information had already been encoded), which has been shown to be particularly difficult for older adults in general (Eich et al., 2017, 2018). Younger and older adults of both sexes completed a pair of tasks in which inhibition was required at different time points: prior to encoding in the Ignore task, and after encoding in the Suppress task. The critical finding was an interaction between the type of inhibition, age group, and sex: while there were no age or sex differences in inhibitory processes when information was to-be-ignored prior to encoding, older women were particularly impaired relative to both younger women and older men when they needed to inhibit information after it had already been encoded. Importantly, older men did not exhibit this impairment relative to younger men. These results provide further support for the presence of memorial inhibitory deficits in older age, but add nuance by implicating biological sex as an important mediator in this relationship, with it more difficult for older women to inhibit what was once relevant in memory.

Why might female older adults be less effective inhibiting information already encoded in working memory? An extensive body of literature supports the notion that women more effectively encode detailed information, while men have greater encoding of gist information (see Herrera et al., 2019). This manifests in women displaying higher recall of peripheral information in emotional scenes and men higher recall of central information (Seidlitz & Diener, 1998), women remembering more fine-grained local details in studies on spatial navigation and men remembering more gist-based "long-distance" spatial representations (Cherney et al., 2008), and women with more accurate and/or faster perceptual processing of local detail-type information in hierarchical stimuli (e.g., Navon figures) and men with more accurate processing of global and central information (Roalf et al., 2006).

In the current study, lure items may represent a "detail," defined in one important study on emotional memory as "peripheral information that has no bearing on the context of the story line" (Heuer & Reisberg, 1990). Here, these lure items are not part of the "story line" (or should not be if they are properly inhibited) as they are supposed to be selected against. Both sexes ignored these details (i.e., the lure words) equally well when they were instructed to do so prior to encoding, consistent with the notion that sex differences may emerge later on during encoding, consolidation, and/or retrieval, and are not due to earlier differences in attentional processing (MacFadden et al., 2003). When suppressing information after presentation, however, women may have already encoded the items in greater detail and, because of this, have a greater burden of IR at retrieval when a lure item is probed. Indeed, supporting this conjecture, there does not appear to be a blanket effect present across all conditions. Rather, our data suggest that women's difficulty in the inhibition of no-longer-relevant stimuli appears to be dependent on when inhibition occurs in the memory-processing stream; that is, in the context of the current tasks, women appear to be able to perceptually ignore items as well as men, but are less effective in memorial inhibition once they are already encoded in working memory.

It is important to note that the tasks were not just more difficult for older adults overall. Despite cognitively healthy older adults exhibiting declines in associative memory (Naveh-Benjamin & Mayr, 2018), accuracy on the tasks was equivalent between age groups, and on a trial level, performance was equated across valid (and control) items, which require the encoding, maintenance, and retrieval of the correct color–word associations. These results suggest that other processes, including age-related source monitoring or working memory capacity differences, do not account for our results in the current study, as the valid trials necessitated the encoding, maintenance, and retrieval of the correct color–word associations. Further, while older adults also typically display deficits in speed of processing (Salthouse, 1996), RTs were equivalent on the Ignore task, but slower for older adults on the Suppress task. These slower RTs on the Suppress task manifested in larger lure–control differences, but only for women. As such, older adults completed the tasks as accurately and quickly as younger adults except on specific, and we argue, critical, trial types which are reflective on inhibitory abilities, with specific deficits for older women showing up when inhibiting to-be-suppressed items from working memory.

According to the dual mechanism of control framework (Braver, 2012), aging is associated with a shift in the reliance on proactive and reactive control processes, such that older adults resort to less efficient, late-stage reactive control processes when early, efficient proactive control measures fail (Paxton et al., 2008). While our findings of increases in RT to correctly reject lure items at the time of the probe for the older women provide additional support for this theory, it is noteworthy that accuracy was equivalent across all group-level comparisons, unlike in other previous reports using the same cognitive tests with different participant groups (Eich et al., 2014). Failing to drop the lure items effectively makes the task more challenging insofar as the working memory load is theoretically double relative to participants who successfully suppressed the irrelevant items. It is notable, then, that despite retaining more information, older women were equally as accurate as the other age/sex groups. It is possible that this may have resulted from women forming richer associative connections between study materials that could serve as more effective retrieval cues, but also lead to more proactive interference in multitrial learning, as has been demonstrated in past work (Bloise & Johnson, 2007). This can be considered an adaptive constructive process (Schacter, 2012), such that information that is initially retained more in depth may be more difficult to inhibit later on. In a sense, then, the deficit in older women's memorial inhibition may represent a double-edged sword, as delays in rejecting to-be-suppressed lure items may be the result of richer and broader encoding processes that more firmly cement these items in memory relative to others. The current study was not equipped to directly test this possibility, but future work could help shed light on whether this is the case, or not.

The current study examined the influence of age and sex on the ability to inhibit information at different stages in the memory-processing stream. Previously utilized methodology (Eich et al., 2017, 2018; Smith et al., 2011) was employed, which required younger and older participants to ignore a subset of information either prior to encoding (i.e., perceptual inhibition) or to suppress a subset of information after encoding (i.e., memorial inhibition). While neither age nor sex influenced inhibition prior to encoding, when information had already been encoded, older women showed a greater cost of to-be-suppressed lure words on RTs relative to younger women and older men. The results of this study are in line with other findings of sex-related divergences in specific cognitive functions starting in midlife, perhaps as a function of cultural, educational, experiential, hormonal, or other yet-to-be-determined factors (Jäncke 2018; cf. Kurth et al., 2020). In sum, these findings add to the literature on inhibitory control and aging and implicate biological sex as an important factor in the ability to suppress information already stored in working memory.

Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences* online.

Funding

This research was supported in part by the National Institute of Health (NIH), National Institute on Aging (NIA) grants (R00AG055684, R01AG026158, and R01AG038465). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NIH/NIA.

Conflict of Interest

None declared.

Data Availability

The specific hypotheses tested in this manuscript were not preregistered. Data will be made available to qualified researchers upon written request.

References

Ahmari, S. E., Eich, T., Cebenoyan, D., Smith, E. E., & Simpson, B. H. (2014). Assessing neurocognitive function in psychiatric disorders: A roadmap for enhancing consensus. *Neurobiology of Learning and Memory*, **115**, 10–20. doi:10.1016/j.nlm.2014.06.011

Anderson, M. C., Reinholz, J., Kuhl, B. A., & Mayr, U. (2011). Intentional suppression of unwanted memories grows more difficult as we age. *Psychology and Aging*, **26**(2), 397–405. doi:10.1037/a0022505

Bessette, K. L., Karstens, A. J., Crane, N. A., Peters, A. T., Stange, J. P., Elverman, K. H., Morimoto, S. S., Weisenbach, S. L., & Langenecker, S. A. (2020). A lifespan model of interference resolution and inhibitory control: Risk for depression and changes with illness progression. *Neuropsychology Review*, **30**(4), 477–498. doi:10.1007/s11065-019-09424-5

Bjorklund, D. F., & Kipp, K. (1996). Parental investment theory and gender differences in the evolution of inhibition mechanisms. *Psychological Bulletin*, **120**(2), 163–188. doi:10.1037/0033-2909.120.2.163

Bloise, S. M., & Johnson, M. K. (2007). Memory for emotional and neutral information: Gender and individual differences in emotional sensitivity. *Memory*, **15**, 192–204. doi:10.1080/09658210701204456

Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences*, **16**(2), 106–113. doi:10.1016/j.tics.2011.12.010

Cherney, I. D., Brabec, C. M., & Runco, D. V. (2008). Mapping out spatial ability: Sex differences in way-finding navigation. *Perceptual and Motor Skills*, **107**(3), 747–760. doi:10.2466/pms.107.3.747-760

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Earlbaum Associates.

Duff, S. J., & Hampson, E. (2001). A sex difference on a novel spatial working memory task in humans. *Brain and Cognition*, **47**(3), 470–493. doi:10.1006/brcg.2001.1326

Eich, T. S., Nee, D. E., Insel, C., & Smith, E. E. (2014). Neural correlates of impaired cognitive control over working memory in schizophrenia. *Biological Psychiatry*, **76**(2), 146–153. doi:10.1016/j.biopsych.2013.09.032

Eich, T. S., Conçalves, B. M. M., Nee, D. E., Razlighi, Q., Jonides, J., & Stern, Y. (2018). Inhibitory selection mechanisms in clinically healthy older and younger adults. *Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, **73**, 612–621. doi:10.1093/geronb/gbw029

Eich, T. S., Razlighi, Q. R., & Stern, Y. (2017). Perceptual and memory inhibition deficits in clinically healthy older adults are associated with region-specific, doubly dissociable patterns of cortical thinning. *Behavioral Neuroscience*, **131**(3), 220–225. doi:10.1037/bne0000194

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology. General*, **133**(1), 101–135. doi:10.1037/0096-3445.133.1.101

Gazzaley, A., Clapp, W., Kelley, J., McEvoy, K., Knight, R. T., & D'Esposito, M. (2008). Age-related top-down suppression deficit in the early stages of cortical visual memory processing. *Proceedings* of the National Academy of Sciences of the United States of America, **105**, 13122–13126. doi:10.1073/pnas.0806074105

Hampson, E. (2018). Estrogens, aging, and working memory. *Current Psychiatry Reports*, **20**(12), 109. doi:10.1007/s11920-018-0972-1

Hasher, L., Lustig, C., & Zacks, R. (2007). Inhibitory mechanisms and the control of attention. In A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. Towse (Eds.), *Variation in working memory* (pp. 227–249). Oxford University Press.

Hasher, L., Stoltzfus, E. R., Zacks, R. T., & Rypma, B. (1991). Age and inhibition. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, **17**(1), 163–169. doi:10.1037//0278-7393.17.1.163

Healey, M. K., Hasher, L., & Campbell, K. L. (2013). The role of suppression in resolving interference: Evidence for an age-related deficit. *Psychology and Aging*, **28**(3), 721–728. doi:10.1037/a0033003

Herlitz, A., & Rehnman, J. (2008). Sex differences in episodic memory. *Current Directions in Psychological Science*, **17**, 52–56. doi:10.1111/j.1467-8721.2008.00547.x

Herrera Ycaza, A., Wang, J., & Mather, M. (2019). The gist and details of sex differences in cognition and the brain: How parallels in sex differences across domains are shaped by the locus coeruleus and catecholamine systems. *Progress in Neurobiology*, **176**, 120–133. doi:10.1016/j.pneurobio.2018.05.005

Heuer, F., & Reisberg, D. (1990). Vivid memories of emotional events: The accuracy of remembered minutiae. *Memory & Cognition*, **18**(5), 496–506. doi:10.3758/bf03198482

Hosseini-Kamkar, N., & Morton, J. B. (2014). Sex differences in self-regulation: An evolutionary perspective. *Frontiers in Neuroscience*, **8**, 233. doi:10.3389/fnins.2014.00233

Jäncke, L. (2018). Sex/gender differences in cognition, neurophysiology, and neuroanatomy. *F1000 Research*, **7**, 805. doi:10.12688/f1000research.13917.1

JASP Team (2020). JASP (Version 0.14.1) (Computer software).

Joormann, J., Nee, D. E., Berman, M. G., Jonides, J., & Gotlib, I. H. (2010). Interference resolution in major depression. *Cognitive, Affective, & Behavioral Neuroscience*, **10**, 21–33. doi:10.3758/CABN.10.1.21

Kerschbaum, H. H., Hofbauer, I., Gföllner, A., Ebner, B., Bresgen, N., & Bäuml, K. T. (2017). Sex, age, and sex hormones affect recall of words in a directed forgetting paradigm. *Journal of Neuroscience Research*, **95**(1–2), 251–259. doi:10.1002/jnr.23973

Kurth, J. A., Miller, A. L., Toews, S. G., Gross, M.,Collier, A., & Ventura, T. (2020). An exploratory study using participation plans for inclusive social studies instruction. *DADD Online Journal*, 6, 158–176.

Lustig, C., & Hasher, L. (2001). Implicit memory is not immune to interference. *Psychological Bulletin*, **127**(5), 618–628. doi:10.1037/0033-2909.127.5.618

MacFadden, A., Elias, L., & Saucier, D. (2003). Males and females scan maps similarly, but give directions differently. *Brain and Cognition*, **53**(2), 297–300. doi:10.1016/s0278-2626(03)00130-1

Maitland, S. B., Herlitz, A., Nyberg, L., Bäckman, L., & Nilsson, L. G. (2004). Selective sex differences in declarative memory. *Memory & Cognition*, **32**(7), 1160–1169. doi:10.3758/bf03196889

McDowd, J. M. (1997). Inhibition in attention and aging. *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, **52**(6), 265–273. doi:10.1093/geronb/52b.6.p265

Miller, D. I., & Halpern, D. F. (2014). The new science of cognitive sex differences. *Trends in Cognitive Sciences*, **18**(1), 37–45. doi:10.1016/j.tics.2013.10.011

Morgan, K. N., Derby, C. A., & Gleason, C. E. (2018). Cognitive changes with reproductive aging, perimenopause, and menopause. *Obstetrics and Gynecology Clinics*, **45**, 751–763. doi:10.1016/j.ogc.2018.07.011

Naveh-Benjamin, M., & Mayr, U. (2018). Age-related differences in associative memory: Empirical evidence and theoretical perspectives. *Psychology and Aging*, **33**(1), 1–6. doi:10.1037/pag0000235

Nee, D. E., & Jonides, J. (2008). Dissociable interference-control processes in perception and memory. *Psychological Science*, **19**(5), 490–500. doi:10.1111/j.1467-9280.2008.02114.x

Paxton, J. L., Barch, D. M., Racine, C. A., & Braver, T. S. (2008). Cognitive control, goal maintenance, and prefrontal function in healthy aging. *Cerebral Cortex*, **18**, **5**, 1010–1028. doi:10.1093/cercor/bhm135

Roalf, D., Lowery, N., & Turetsky, B. I. (2006). Behavioral and physiological findings of gender differences in global–local visual processing. *Brain and Cognition*, **60**(1), 32–42. doi:10.1016/j.bandc.2005.09.008

Robert, M., & Savoie, N. (2006). Are there gender differences in verbal and visuospatial working-memory resources? *European Journal of Cognitive Psychology*, **18**, 378–397. doi:10.1080/09541440500234104

Rozek, E., Kemper, S., & McDowd, J. (2012). Learning to ignore distracters. *Psychology and Aging*, **27**(1), 61–66. doi:10.1037/a0025578

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review*, **103**(3), 403–428. doi:10.1037/0033-295x.103.3.403

Saylik, R., Raman, E., & Szameitat, A. J. (2018). Sex differences in emotion recognition and working memory tasks. *Frontiers in Psychology*, **9**, 1072. doi:10.3389/fpsyg.2018.01072

Schacter, D. L. (2012). Adaptive constructive processes and the future of memory. *The American Psychologist*, **67**(8), 603–613. doi:10.1037/a0029869

Seidlitz, L., & Diener, E. (1998). Sex differences in the recall of affective experiences. *Journal of Personality and Social Psychology*, **74**(1), 262–271. doi:10.1037//0022-3514.74.1.262

Shanmugan, S., & Epperson, C. N. (2014). Estrogen and the prefrontal cortex: Towards a new understanding of estrogen's effects on executive functions in the menopause transition. *Human Brain Mapping*, **35**(3), 847–865. doi:10.1002/hbm.22218

Smith, E. E., Eich, T. S., Cebenoyan, D., & Malapani, C (2011). Intact and impaired cognitive-control processes in schizophrenia. *Schizophrenia Research*, **126**(1–3), 132–137. doi:10.1016/j.schres.2010.11.022

Stern, Y., Habeck, C., Steffener, J., Barulli, D., Gazes, Y., Razlighi, Q., Shaked, D., & Salthouse, T. (2014). The Reference Ability Neural Network Study: Motivation, design, and initial feasibility analyses. *Neuroimage*, **103**, 139–151. doi:10.1016/j.neuroimage.2014.09.029

Stoet, G. (2010). Sex differences in the processing of flankers. *The Quarterly Journal of Experimental Psychology*, **63**, 633–638. doi:10.1080/17470210903464253

Stoet, G. (2017). Sex differences in the Simon task help to interpret sex differences in selective attention. *Psychological Research*, **81**(3), 571–581. doi:10.1007/s00426-016-0763-4

Sylvain-Roy, S., Lungu, O., & Belleville, S. (2015). Normal aging of the attentional control functions that underlie working memory. *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, **70**(5), 698–708. doi:10.1093/geronb/gbt166

Tipper, S. P. (2001). Does negative priming reflect inhibitory mechanisms? A review and integration of conflicting views. *The Quarterly Journal of Experimental Psychology A*, **54**, 321–343. doi:10.1080/713755969

Titz, C., & Verhaeghen, P. (2010). Aging and directed forgetting in episodic memory: A meta-analysis. *Psychology and Aging*, **25**(2), 405–411. doi:10.1037/a0017225

Voyer, D., Voyer, S. D., & Saint-Aubin, J. (2017). Sex differences in visual-spatial working memory: A meta-analysis. *Psychonomic Bulletin & Review*, **24**(2), 307–334. doi:10.3758/s13423-016-1085-7

Wagenmakers, E. J., Verhagen, J., Ly, A., Matzke, D., Steingroever, H., Rouder, J. N., & Morey, R. D. (2017). The need for Bayesian hypothesis testing in psychological science. In S. O. Lilienfeld & I. D. Waldman (Eds.), *Psychological science under scrutiny: Recent challenges and proposed solutions* (pp. 123–138). Wiley Blackwell. doi:10.3758/s13423-017-1323-7

Wnuczko, M., Pratt, J., Hasher, L., & Walker, R. (2012). When age is irrelevant: Distractor inhibition and target activation in priming of pop-out. *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, **67**(3), 325–330. doi:10.1093/geronb/gbr114

Yang, H., Yang, S., & Park, G. (2013). Her voice lingers on and her memory is strategic: Effects of gender on directed forgetting. *PLoS One*, **8**, e64030. doi:10.1371/journal.pone.0064030