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Positive information facilitates response inhibition in older adults only when emotion is task-relevant

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Abstract

Emotional information is integral to everyday life and impacts a variety of cognitive abilities including response inhibition, a critical skill for maintaining appropriate and flexible behaviour. However, reported effects of emotion on response inhibition are inconsistent in younger adults, and very limited in older adults. Effects of aging are especially relevant because emotion regulation improves with aging despite declining inhibitory control over neutral information. Across three studies, we assessed the impact of emotional facial expressions on response inhibition in younger and older adults while manipulating attention to task stimuli. Emotional faces (versus neutral faces) altered response inhibition only when task instructions required explicit attention to emotional attributes of the faces. When directly comparing fear faces to happy faces, both age groups had better response inhibition to happy faces. Age further influenced differences across conditions, in that happy faces enhanced response inhibition relative to neutral faces in older adults but not younger adults. Thus, emotional response inhibition for task-relevant (but not task-irrelevant) positive information is enhanced in late life compared to early adulthood. The present work extends the nascent literature on emotional response inhibition in aging, and proffers a framework to reconcile the mixed literature on this topic in younger adults.

Keywords

emotion; response inhibition; aging; executive function; stop-signal task

Introduction

Emotion processing is integral to everyday life, and impacts a variety of cognitive abilities, including executive functioning (Pessoa, 2009; Prehn et al., 2011). One well-characterised executive function is response inhibition (i.e., the ability to stop a motor response), which is

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SW and JW conceived and designed the study, collected the data, and conducted the data analyses. SW, JW, and EL drafted and revised the manuscript. All authors granted approval for publication of the content.

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The data that support the findings of this study are available from the corresponding author, SW, upon reasonable request.

important for maintaining safe, appropriate, and flexible behaviour (Verbruggen & Logan, 2008). Effects of emotion on response inhibition, however, are inconsistent, with studies collectively showing emotion can impair, facilitate, or have no effect on motor response inhibition in younger adults (Zinchenko et al., 2020). In some cases positive and negative images impaired response inhibition compared to neutral images (Kalanthroff et al., 2013; Lindström & Bohlin, 2012; Patterson et al., 2016; Rebetez et al., 2015; Verbruggen & De Houwer, 2007), while in other studies emotional faces (e.g., angry, fear, happy) facilitated response inhibition compared to neutral faces (Pawliczek et al., 2013; Pessoa et al., 2012; Schel & Crone, 2013). Further, some studies reported no differences between response inhibition for emotional versus neutral stimuli (Goldstein et al., 2007; Sagaspe et al., 2011; Shafritz et al., 2006). Thus, presently there is little consensus about the conditions in which emotion may impair, facilitate, or have no effect on response inhibition. Given the daily relevance of emotion processing and response inhibition, it is important to clarify how these constructs interact.

In addition to the mixed effects of emotional and neutral stimuli on response inhibition, aging may also influence the impact of emotion on response inhibition. While the literature on emotional response inhibition (i.e., the ability to stop a motor response to emotional information) has focused almost exclusively on younger adults, effects of aging are especially relevant because emotion regulation improves with aging (Carstensen, 2006) despite declining inhibitory control over neutral information (Bloemendaal et al., 2016; Gazzaley & D’Esposito, 2007; Smittenaar et al., 2015). Although older adults respond more slowly and are less likely than younger adults to inhibit responses to neutral information (Bloemendaal et al., 2016; Smittenaar et al., 2015), older adults respond more accurately than younger adults on executive functioning and memory tasks employing positive stimuli (Carstensen & Mikels, 2005; Waring et al., 2019; Zinchenko et al., 2017, 2018). Older adults may have chronically active emotion regulation processes engaged, permitting greater control over responses to emotional information, and consequently better task performance. Indeed, older adults apply emotion regulation to disengage from negative stimuli and focus their attention on positive stimuli (Kryla-Lighthall & Mather, 2009; Reed & Carstensen, 2012). Thus, increased control over responses to positive stimuli may lead to improved performance on cognitive tasks using emotional stimuli. In one of the only published investigations directly contrasting emotional response inhibition in younger versus older adults, we reported older adults had fewer false alarms to emotional faces than younger adults in a Go/No-Go task (Waring et al., 2019). Younger (but not older) adults had elevated false alarm rates to positive (versus negative) faces, indicating older adults had more accurate response inhibition for positive stimuli compared to younger adults. In addition to response accuracy (e.g., false alarm rate), another way to assess response inhibition is by the amount of time needed to stop one’s responses; shorter times to actively stop responses reflect more efficient response inhibition. Although effects of emotion on older adults’ response inhibition efficiency (instead of accuracy) are presently unknown, previous research and the framework of the positivity effect suggest positive (versus negative) stimuli may facilitate relatively better response inhibition in older than younger adults.

Presently, multiple factors limit the ability to draw conclusions about age-related changes in emotional response inhibition, including substantial inconsistencies in younger adult findings and very limited older adult research. Several factors may explain mixed reports in younger adults, including differences in emotion's impact on proactive versus reactive response inhibition. Proactive response inhibition, which is often measured using a Go/No-Go task, allows preparation for stopping an action, while reactive response inhibition, which is often measured using a stop-signal task, requires cancelling an ongoing response in real time (Bloemendaal et al., 2016; Braver, 2012; Swick et al., 2011). Although proactive response inhibition (e.g., Go/No-Go task accuracy) is sustained with aging (Kleerekooper et al., 2016), older adults may have slower (i.e., less efficient) reactive response inhibition for neutral stimuli, compared to younger adults (Bloemendaal et al., 2016). It is currently unknown how emotional stimuli, such as fear or happy faces, impact older versus younger adults' reactive response inhibition, although positivity effect literature would suggest more efficient reactive response inhibition to happy faces compared to fear faces. Another factor that may impact response inhibition is task-relevance of a stimulus' emotional attributes (i.e., whether overt attention to the emotional attributes of a stimulus is necessary for task performance; Barratt & Bundesen, 2012; Puls & Rothermund, 2018; Victeur et al., 2019). Several studies in younger adults lend support to the contingent capture hypothesis, which argues emotional stimuli capture attention only when relevant to specific task goals (Tannert & Rothermund, 2018; Victeur et al., 2019). For example, when Victeur and colleagues (2019) manipulated the task-relevance of emotional attributes in a spatial cueing task, participants allocated their attention to fear faces only when they were relevant to the cueing task instructions. It is unclear if the contingent capture hypothesis may operate differently in older versus younger adults, but the positivity effect may be a relevant consideration in this context as well.

Present Study

Across three studies, our goal was to understand how emotion influences response inhibition in younger and older adults in the context of differing task demands. Due to reports of declining inhibitory control to neutral information in older adults (Bloemendaal et al., 2016; Gazzaley & D'Esposito, 2007; Smittenaar et al., 2015), we predicted less efficient overall response inhibition in older than younger adults. Further, drawing upon the limited evidence from past studies employing emotional faces in younger adults as well as the extensive literature of the positivity effect in late life, we predicted emotional (e.g., fear and happy) faces would facilitate more efficient stopping than neutral faces in both age groups, and the faciliatory effect of happy faces would be more pronounced for older adults. Fear and happy faces were used as negative and positive stimuli, respectively, to extend previous younger adult literature (Pessoa et al., 2012; Sagaspe et al., 2011; Schel & Crone, 2013; Waring et al., 2019), and because literature suggests a more robust distinction between fear and neutral facial expressions, and between happy and neutral facial expressions than between more ambiguous expressions like angry and sad faces (Tottenham et al., 2011). Reactive emotional response inhibition was measured using an emotional stop-signal task. Task instructions subtly differed between three studies to explore the effects of manipulating which stimulus attributes of emotional and neutral facial stimuli were relevant for correctly stopping (i.e., inhibiting) a button-press response. In Study 1 and 2, focus on emotional attributes of the stimulus was not necessary to correctly follow task instructions (e.g., Study 1: stop responses for all faces; Study 2: stop responses for male faces but respond for female faces).

In contrast, Study 3 made direct focus on emotional attributes of each stimulus necessary to correctly follow task instructions (e.g., stop responses for fear faces, but respond for happy or neutral faces).

Study 1

Materials and Methods

Participants and Enrolment—Forty younger adults (23 females; age M = 19.12 ± 1.68 years; age range 17–27; years education M = 12.62 ± 0.98) and 41 older adults (24 females; age M = 68.41 ± 5.89 years; age range 60–83; years education M = 15.45 ± 2.31) were included in analyses. Data from 5 additional participants were excluded from analyses due to poor task performance (1 younger and 2 older adults), failure to complete the task (1 older adult), and researcher error (1 older adult). Sample race, ethnicity, and handedness are reported in Supplemental Materials.

Participants were community dwelling native English speakers. Exclusion criteria included uncorrected vision or hearing problems, prior or present diagnosis or treatment for any psychiatric conditions, diagnosis of Autism Spectrum Disorder or Asperger's Syndrome, colour-blindness, history of stroke or severe head injury, or history of alcoholism or substance abuse within the last 6 months. Additional exclusion criteria for younger adults included prior or present diagnosis or treatment for attention-deficit/hyperactivity (ADHD) or neurological disorder. Additional exclusion criteria for older adults included life-shortening illness (e.g., cancer), dementia, neurodegenerative illness (e.g., Parkinson's disease, cerebrovascular disease), or current use of any central nervous system (CNS)-altering medication, which included psychotropic medications as well as any other medications with CNS effects (e.g., centrally acting anticholinergics and antihistaminergics, opioids, GABAergics, and dopaminergics).

The research protocol was approved by the Institutional Review Boards of Saint Louis University and Washington University in St. Louis in accordance with the Declaration of Helsinki. All participants provided written informed consent and HIPAA authorisation. Younger adult participants were from the Saint Louis University student population who were taking psychology courses. They were recruited through an online system (SONA Systems, Bethesda, MD, USA) and screened for eligibility with an anonymous questionnaire (Qualtrics, Provo, UT, USA). Older adult participants were recruited from the St. Louis, MO area through fliers and ads posted in local newspapers, online via Craigslist, and the Washington University Volunteers for Health Recruitment Enhancement Core's Research Participant Registry (https://sites.wustl.edu/wuvfh/), and were screened for eligibility via a short phone interview. Older adult data collection was performed at Saint Louis University, with additional older adults enrolled at Washington University in St. Louis. There were no significant differences in demographics between older adults enrolled at the two sites (see Supplemental Materials). Younger adults were compensated via course credit for research participation, and older adults were paid for their time.

An *a priori* power analysis for sample size needed was based on a repeated measures analysis of variance (ANOVA) with an interaction of between-subjects factor of age (e.g., 2 groups; younger adults and older adults) and within-subjects factor of stop condition (e.g., 3 measurements; fear, happy, or neutral stop signals). The power analysis was computed using G*Power Version 3.1 (Faul et al., 2007). The power analysis for a small-to-medium effect size ($f = 0.2$), 0.01 alpha error probability (2-tailed), and 90% power determined a total sample of $N = 76$ would yield sufficient power to detect effects within each study. To remain sufficiently powered in the case of missing data or poor task performance, Study 1, as well as the subsequent two studies, enrolled at least 80 participants each (i.e., 40 younger adults and 40 older adults).

Emotional Stop-Signal Task Stimuli and Design

The stop-signal task used (see Figure 1 for task schematic) was originally designed by Pessoa, Padmala, Kenzer, and Bauer (2012) and previously employed with a sample of only younger adults. The task presents a human face displaying a fear, happy, or neutral expression as an infrequent stop-signal, which cues the participant to withdraw a motor response in-progress (Verbruggen et al., 2019; Verbruggen & Logan, 2008). The independent race model underlies the stop-signal task, and has been described previously (Band et al., 2003; Logan, 1994; Verbruggen et al., 2019; Verbruggen & Logan, 2008). To briefly summarize, the independent race model proposes that two processes, a “go” and a “stop” process, race against one another to determine whether a participant either successfully inhibits or fails to inhibit their motor response on a given trial (Congdon et al., 2012; Verbruggen et al., 2019). The stop-signal task allows for the covert estimation of a stop-signal reaction time, which indirectly measures the time needed to stop an ongoing motor response. As replicated from Pessoa and colleagues (2012), face stimuli were drawn from four published face stimulus sets (Ekman & Friesen, 1976; Ishai et al., 2004; Lundqvist et al., 1998; Tottenham et al., 2009). In the present study, participants saw each face image only once. Across task blocks, facial identities could be seen posed in more than one expression (i.e., identity A posed with fear, happy, and neutral expressions). All face images were approximately 8.5 cm high by 6.5 cm wide and presented in greyscale within an oval frame cropped to exclude hair styles (depicted in Figure 1).

The stop-signal task was programmed using Presentation (Version 18.3; Neurobehavioral Systems, Berkeley, CA, USA) on a Hewlett-Packard ProBook (Palo Alto, CA, USA) running Microsoft Windows (Version 7 Enterprise; Redmond, WA, USA). There were 900 experimental trials over six blocks (i.e., 150 trials per block). The six task blocks presented 120 go trials and 30 stop trials, using a 4:1 ratio of go to stop trials to ensure responding became an over-learned response. In go trials, participants distinguished between a circle or square by pressing the left or right arrow key, respectively. Participants were instructed to respond as quickly and accurately as possible on go trials. The go trials were balanced for circle and square trials within and across blocks (i.e., 450 circle trials total, and 75 circle trials per block). Presentation of circles versus squares in a given trial was counterbalanced between participants. Trials were presented in a pseudo-randomised order. During stop trials, which consisted of all face types, participants were instructed to stop their response when a face appeared on the computer screen. The stimulus set comprised 180 images of faces and was similar to the set employed by Pessoa and colleagues (2012). Stop trials were divided equally among conditions (e.g., 10 fear, 10 happy, and 10 neutral faces per block; 60 fear, 60 happy, and 60 neutral faces in total). Gender of the faces was also evenly balanced among stop conditions.

Each go stimulus remained on the screen for a fixed duration of 1000 milliseconds (ms) and was followed by a blank screen for 1000ms in all three studies. During stop trials, a face (e.g., fear, happy, or neutral expressions) appeared inside the go stimulus after a variable delay. The stop-signal delay (i.e., the delay period from the go stimulus onset to stop-signal onset within trial) adjusted adaptively in 50ms increments in response to performance on the previous stop trial. For example, if the response was not successfully inhibited, then the stop-signal delay shortened by 50ms on the next trial to improve the chance of successful inhibition; if the response was successfully inhibited then the next stop-signal delay lengthened by 50ms to increase task difficulty. The stop-signal delay for each stop-signal condition (i.e., fear, happy, neutral) was computed independently of the other two stop-signal conditions; thus, a unique, adaptive stop-signal delay was computed for each of the three stop-signal conditions for each participant. The dynamic adjustment of the stop-signal delay ensures approximately 50% success rate for each stop-signal condition, which allows for reliable calculation of stop-signal reaction times (Logan, 1994; Verbruggen et al., 2019). As stated by Congdon and colleagues (2012), the 50% success rate represents the point at which the independent race results in a tie, providing an individual average measure of response inhibition. Simulations by Verbruggen and colleagues (2019) indicate reliable and unbiased stop-signal reaction time group-level estimates can be obtained when there are at least 25 successful stop trials per person. Given that the present task had 60 stop trials per emotion condition, the 50% success rate ensured approximately 30 stop trials per emotion condition for each participant. The equal importance of go and stop trials was emphasized in task instructions. Participants performed a short practice block to confirm understanding and adherence to instructions before starting the task.

Measures

Participants completed several neuropsychological measures to characterise executive functioning, and to confirm the older adult sample was cognitively normal. A description of the measures administered is included in Supplemental Materials. Relevant results, including means, standard deviations, and one-way ANOVAs across study versions for younger and older adults separately are reported in Tables S1 through S4. Older adults were cognitively non-impaired, as indicated by Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) scores of 26 or above (reported in Table S4).

Data Analysis

Accuracy of go trials was inspected to aid interpretation of the response inhibition outcome measure (Verbruggen et al., 2019). Task blocks with more than 33% incorrect go trials (e.g., no response given or selected incorrect key) were removed from analyses for that individual. Data from participants with fewer than four blocks (out of six blocks total) with at least 66% go trial accuracy were removed from analyses entirely (See Table 1 for descriptive statistics of go trials including mean of participants' median go response times by study and age group; See Supplemental Materials for comparison of go response times by age group and study version). The response inhibition outcome measure was the stop-signal reaction time, which was computed by subtracting each participant's mean stop-signal delay for each stop-signal condition from their correct go trial median response time (i.e., each participant has three unique stop-signal reaction time values, indexing time needed to stop for fear, happy, and neutral faces, respectively). Stop-signal reaction time was estimated using the median method instead of the mean method because it is less influenced by a skewed response time distribution (Verbruggen & Logan, 2009). Given that the time associated with response inhibition (i.e., stopping a motor response) cannot be observed directly, the subtraction allows for the covert estimation of this latent variable, and has been used consistently across a broader response inhibition literature (Logan, 1994; Verbruggen et al., 2019; Verbruggen & Logan, 2008). Maintaining use of this methodology allows the present results to be appreciated within an inconsistent literature. Notably, stop-signal reaction times contribute unique variance above processing speed alone (Bedard et al., 2002; Logan, 1994). A repeated measures ANOVA on stop-signal reaction times assessed main and interactive effects of within-subject factor stop-signal condition (i.e., fear, happy, neutral) and between-subjects factor age group (i.e., younger, older adults). To further examine significant interactive effects, planned follow-up 2-tailed, paired t-tests within each age group compared differences between specific conditions (i.e., stop-signal reaction time differences between stop-signal conditions within each age group).

Results and Interim Discussion

The repeated measures ANOVA revealed a main effect of age on stop-signal reaction times ($F(1,79) = 23.30$, $p < .001$, $\eta_p^2 = .23$). Older adults had longer stop-signal reaction times than younger adults, indicating poorer response inhibition (see Figure 2A; means and standard deviations are reported in Table 2. There was no main effect of condition or interaction of condition with age (Fs$(2,158) < 1.35$, ps $> .26$, all $\eta_p^2 < .02$).

As predicted, older adults were less efficient at stopping (i.e., needed more time to stop their response) compared to younger adults. However, emotion did not impact response inhibition performance within either age group, indicating a similar pattern of results for younger and older participants, which did not differ as a function of whether the stop-signal condition was emotional or neutral. Based on previous literature, we theorised that the lack of effect of emotion condition was due to shallow processing of the stop-signal stimuli (Mitchell et al., 2007), in that participants did not need to attend to attributes of the stop-signal faces to decide whether to stop their response; they merely needed to notice that any face had appeared on the screen.

Study 2

Given the results of Study 1 and those of Mitchell and colleagues (2007), we next sought to test whether the results of Study 1 could be attributable to incomplete or shallow processing of the faces serving as stop-signals. Study 2 task instructions required deeper processing and evaluation of the face serving as the stop-signal to achieve correct task performance. Participants were instructed to decide whether to stop their response based on specific attributes of the faces in the stop-signals. Specifically, Study 2 instructed participants to discriminate the gender of the face to determine whether to inhibit or complete their response, thereby requiring deeper stimulus processing than Study 1, yet still without requiring overt focus on emotional attributes (i.e., expression) of the faces. In Study 2, we maintained our original hypotheses, predicting that requiring deeper processing of the emotional faces would facilitate more efficient stopping than neutral faces in both age groups, and the faciliatory effect of happy faces would be more pronounced for older adults.

Materials and Methods

Participants—Forty younger adults (22 females; age M = 18.70 ± 0.76 years; age range 17–20; years education M = 12.45 ± 0.64) and 39 older adults (24 females; age M = 69.41 ± 6.49 years; age range 60–86; years education M = 16.67 ± 3.29) were included in Study 2 analyses. Data from 6 additional participants were excluded from analyses due to poor task performance (3 older adults) and research errors during data collection (3 younger adults). Sample race, ethnicity, and handedness are reported in Supplemental Materials. Participants were recruited via the same methods and met the same inclusion and exclusion criteria as participants in Study 1, and participants in Study 1were not allowed to enrol in Study 2. Again, there were no significant differences in demographics between older adults enrolled at Saint Louis University versus Washington University in St. Louis (see Supplemental Materials).

Materials and Procedure—The Study 2 stop-signal task presented go and stop trials as in Study 1, and additionally included "go-face" trials. During go-face trials participants were instructed to respond to selected faces that appeared inside the go stimulus after a variable delay. The go stimulus appeared for a fixed duration of 1200ms to ensure adequate decision time during stop and go-face trials. Gender of the face was used as the stop-signal cue; participants were instructed to stop their response based on the gender of the faces (e.g., do not respond when you see a male face, and do respond when you see a female face, or vice versa; in this example, female faces are go-face trials). The stimulus set comprised 360 images of faces, each viewed once by each participant. The six task blocks each consisted of 90 go trials, 30 go-face trials, and 30 stop trials. The go-face and stop trials were each equally divided among conditions (e.g., 10 fear, 10 happy, and 10 neutral faces per block). For three consecutive task blocks, male faces were used as stop-signals and female faces were used as go-face signals, and vice versa for the other three consecutive task blocks. The three blocks for each instruction were presented consecutively instead of alternately in order to reduce participant confusion for current block task instructions. Participants had the opportunity to practice the task at the outset and again when the instructions changed to assure they understood and retained the instructions for the next series of blocks (e.g., which gender of face were stop trials and which were go-face trials). The gender of the initial stop-signal condition was counterbalanced between participants.

Results and Interim Discussion

The repeated measures ANOVA revealed no main effects of age or condition on stop-signal reaction times, or interaction between age and condition (Fs < 1.18, ps > .31, all $\eta_p^2 < 0.02$). Deeper processing of facial attributes, but without overt focus on facial expressions, did not alter response inhibition to emotional information. Additionally, task instructions to evaluate gender of the face eliminated the main effect of age observed in Study 1. Younger and older adults performed similarly across emotion conditions, as well as compared to one another (see Figure 2B; means and standard deviations are reported in Table 2).

In Study 2 emotional attributes of the faces were irrelevant to task instructions, which may explain similarities in response inhibition performance across conditions. As observed in Study 1, these results may be another instance where emotional stimuli fail to impact response inhibition when the emotional attributes are irrelevant to the task goals (Folk et al., 1992; Victeur et al., 2019). The faces serving as stop-signals (and as go-face trials) were presented in greyscale, and without makeup or visible hairstyles that could provide simple cues to gender, so in order to respond correctly participants needed to evaluate the facial features. Yet in spite of focusing participants' attention on facial features (i.e., which are also the source of relevant cues about facial expression) to identify gender, no effects of condition on response inhibition were present. There were also no main or interactive effects of age, so it appears the deeper stimulus processing required to identify gender, and therefore discriminate the faces that necessitate "go" versus "stop" responses, evokes similar stopping efficiency in both younger and older adults.

Study 3

The results from Study 1 and Study 2 together showed that, regardless of whether participants applied shallow or deep stimulus processing, when the emotional attributes of the facial stimuli were irrelevant to the task instructions, response inhibition performance did not differ across the emotional and neutral stop-signal conditions. To test the possibility that similar performance across emotion conditions in Study 1 and 2 were due to emotional attributes of stimuli being task-irrelevant (Puls & Rothermund, 2018; Victeur et al., 2019), we next sought to investigate the pattern of response inhibition when focusing on emotional information was directly relevant to task performance. Study 3 examined if instructions to overtly evaluate the emotional expression of the face stimuli to determine response behaviour would impact the patterns of inhibition performance between conditions or age groups. Thus, in Study 3, participants were instructed to discriminate the emotional expression of the faces shown to decide whether to inhibit or complete their response. Although the hypothesized effects of stop condition on response inhibition was not supported in Study 1 and Study 2 (i.e., when focus on emotion was task-irrelevant), in Study 3 we predicted overt focus on emotional attributes would facilitate response inhibition for emotional faces compared to neutral faces. Additionally, considering the extensive literature reporting differing effects of emotion on cognition between younger and older adults (Mather, 2012), including when focus on emotion is task-relevant to response inhibition (Waring et al., 2019), we hypothesized an interaction between age and stop condition. We expected that although older adults would be slower overall compared to younger adults, the faciliatory effect of positive stimuli on response inhibition would be stronger in older adults compared to younger adults.

Materials and Methods

Participants—Forty-two younger adults (26 females; age M = 19.29 ± 1.42 years; age range 18–26; years education M = 12.57 ± 0.83) and 40 older adults (24 females; age M = 70.30 ± 5.69 years; age range 61–85; years education M = 16.70 ± 3.08) were included in analyses. Data from 5 additional participants were excluded from analyses due to poor task performance (3 younger adults) or not understanding task instructions (2 older adults). Sample race, ethnicity, and handedness are reported in Supplemental Materials. Participants were recruited and met the same inclusion and exclusion criteria as participants in Study 1 and 2, and participants in Study 1 and 2 were not allowed to enrol in Study 3. All Study 3 older adult participants were recruited from Saint Louis University only.

Materials and Procedure—As in Study 2, the go stimulus appeared for a fixed duration of 1200ms. In Study 3, facial expression was used as stop-signal cue, in that participants were instructed to stop their response based on the facial expression of the faces (e.g., do not respond when you see a fear face, and do respond when you see a happy or neutral face). The stimulus set comprised 360 images of faces, each viewed once by each participant. Each of the six blocks consisted of 90 go trials, 30 go-face trials, and 30 stop trials. Go-face trials in a given block were equally divided between two conditions (e.g., 15 happy and 15 neutral faces), while stop trials in a given block depicted one emotional expression (e.g., 30 fear faces). Across the six task blocks, fear, happy, and neutral expressions each served as stop-signals for two contiguous blocks, and the sequence of blocks was counterbalanced across participants. The two blocks for each instruction were presented consecutively instead of alternately in order to reduce participant confusion for current block task instructions. Participants had the opportunity to practice the task at the outset and again each time the instructions changed to assure participants understood and retained the instructions for the next series of blocks (i.e., which facial expressions were stop trials and which were go-face trials).

Results and Interim Discussion

The repeated measures ANOVA revealed a main effect of stop-signal condition on stop-signal reaction times ($F(2,160) = 9.19$, $p < .001$, $\eta_p^2 = .11$) qualified by an interaction of condition and age ($F(2,150) = 3.17$, $p = .04$, $\eta_p^2 = .04$). There was no main effect of age ($F(1,80) = 1.98$, $p = .16$, $\eta_p^2 = .03$). Study 3 showed that when emotional attributes of the stimulus were task-relevant, response inhibition performance varied by condition (see Figure 2C; means and standard deviations are reported in Table 2). When participants overtly evaluated stimulus facial expressions, fear faces evoked longer stop-signal reaction times compared to neutral and happy faces in younger adults (fear > neutral: $t(41) = 2.00$, $p = .03$, $d = .57$; fear > happy: $t(41) = 3.00$, $p = .01$, $d = .59$; neutral vs. happy: $t(41) = 0.20$, $p = .90$, $d = .04$), while fear and neutral faces evoked longer stop-signal reaction times compared to happy faces in older adults (fear vs. neutral: $t(39) = 0.30$, $p = .80$, $d = .05$; fear > happy: $t(39) = 4.00$, $p < .001$, $d = .70$; neutral > happy: $t(39) = 4.00$, $p < .001$, $d = .73$).

When overt focus on emotional information was relevant for task performance and drawing directly comparison between fear and happy conditions, we observed that happy faces facilitated response inhibition compared to fear faces in both younger and older adults. In older adults, happy faces additionally facilitated response inhibition compared to neutral faces. However, in younger adults, attending to emotion compared to neutral did not produce additional faciliatory effects on response inhibition; in contrast, younger adults demonstrated impaired inhibition for fear faces compared to neutral. Given the similarity of instructions used in Studies 2 and 3, which both required focus on facial features, these findings suggest task-relevant emotional information, but not cognitive demand alone, impacts response inhibition performance in both younger and older adults. However, aging introduces further nuance to the findings. Whereas older adults have greater response inhibition for happy faces than neutral faces, younger adults have poorer response inhibition for fear faces than neutral faces. When overt focus on emotion is required for task performance, positive emotion facilitates response inhibition in older adults, whereas negative emotion impairs response inhibition in younger adults.

General Discussion

We conducted three behavioural studies examining effects of emotion and age on response inhibition to extend the very limited research on this topic in older adults. Task instructions differed between studies to manipulate which stimulus attributes were relevant for deciding stopping behaviour, with the goal of clarifying how varying one’s focus impacts emotional response inhibition. Across three studies, we predicted emotional faces (compared to neutral) would facilitate response inhibition in younger and older adults. The key outcome was that emotion condition impacted response inhibition only when participants needed to focus directly on the emotional attributes of facial expressions to make their stopping decisions. When focus on emotional attributes was not relevant to task instructions (i.e., Studies 1 and 2), no differences between stop-signal conditions emerged. Notably, in Study 3, when directly comparing fear faces to happy faces, both younger and older adults had better response inhibition to happy faces, indicating focus on emotional aspects of the stimuli affects response inhibition.

The differences between emotion conditions were further nuanced by age when focus on emotional attributes was task-relevant. Negative information impaired response inhibition in younger adults, while positive information facilitated response inhibition in older adults. We expected response inhibition to *positive* (versus negative) stimuli would be more impaired in younger than older adults, as we reported recently (Waring et al., 2019), but instead discovered *negative* information impaired response inhibition in younger adults (and only in Study 3). One plausible explanation for inconsistent results is the distinction between implementing proactive versus reactive inhibition (Braver, 2012; Swick et al., 2011). When emotional information is task-relevant, it may differentially alter patterns of proactive versus reactive emotional response inhibition.

Given that age-related declines in inhibition of responses to neutral information are reported consistently (Gazzaley & D’Esposito, 2007; Smittenaar et al., 2015), we predicted older adults would exhibit overall poorer response inhibition (e.g., longer stop-signal reaction times) than younger adults. Study 1 supported our hypothesis, as younger adults had more efficient response inhibition than older adults across emotional and neutral task conditions, but when cognitive demands increased in studies 2 and 3 (by requiring overt attention to specific attributes of facial expressions), younger and older adults had comparable stopping efficiency across conditions. Drawing upon positivity effect literature (Reed et al., 2014; Reed & Carstensen, 2012), we also anticipated positive stimuli would promote more faciliatory effects on stopping ability in older than younger adults. Study 3 supported this predicted interaction of age and stop-signal condition: negative information impaired response inhibition (relative to neutral) in younger adults, while positive information facilitated response inhibition (relative to neutral) in older adults. Younger adults are more sensitive to negative stimuli than older adults (Carstensen & Mikels, 2005; Scheibe & Carstensen, 2010), which may explain their impaired response inhibition to fear faces. The presence of a positivity bias, in that positive information compared to neutral facilitated stopping efficiency for older adults only, supports previous positivity effect literature (Reed et al., 2014). Across a broad literature, Reed and colleagues (2014) demonstrated a robust positivity effect in older adults, although the effect attenuated when task instructions narrowed available cognitive resources. Future studies could investigate how using task-relevant emotional stimuli in less constrained study contexts may impact response inhibition. Overall, the present set of studies suggests emotional response inhibition may be better in older adults than younger adults when task goals require explicit focus on positive stimuli attributes (Reed & Carstensen, 2012).

Taken together, results of these three studies collectively support the contingent capture hypothesis (Folk et al., 1992), which asserts emotional stimuli impact performance only when relevant to specific task goals. Exploratory analyses confirmed task instructions significantly interacted with age and emotion (see Supplemental Materials). Considering whether task instructions dictate that focus on emotion is task-relevant or task-irrelevant may offer insight into inconsistencies across the emotional response inhibition literature. The present series of studies and our previous investigation of emotional response inhibition in aging (Waring et al., 2019) may be reconciled in light of this consideration. In Study 1 and 2, emotion was task-irrelevant and results yielded no influence of emotion on response inhibition. In contrast, instructions for Study 3 and our previous study (Waring et al., 2019) both made overt focus on emotional stimulus attributes task-relevant. Moreover, subtle differences in the direction of interactive effects of age and emotion between Study 3 and our previous study may be explained by differing task demands. Proactive stopping (e.g., Go/No-Go task, as in Waring et al., 2019) may lead to differing engagement with emotional stimuli than the reactive stopping required for stop-signal tasks (e.g., Study 3; Braver, 2012; Swick et al., 2011). Our conclusions advance understanding of how emotion, executive function, and aging interact, and also identify additional avenues to pursue. We recommend future studies consider whether overt focus on the emotional attributes of task stimuli is directly relevant to task instructions, and also consider the proactive versus reactive nature of stopping, when drawing conclusions about how emotion and aging impact executive function.

Limitations and Future Directions

One limitation of this study is that although the faces employed have been widely used in response inhibition studies (e.g., Pessoa et al., 2012; Schel & Crone, 2013), we did not collect individual stimulus ratings from participants, which could confirm consistent interpretation of facial expressions. The possibility of age differences in emotion recognition is a consideration, although we believe the data are better explained by the task instructions manipulation than age differences in recognition of faces. Notably, emotion recognition literature demonstrates a distinction between age differences in labelling emotions versus discriminating between emotions. Although Ruffman and colleagues' (2008) meta-analysis found older adults are less accurate at labelling some emotions (e.g., sad, angry, fear, etc), the results are less consistent for effects of age on emotion discrimination (e.g., picking the angry face between two options of a happy and angry face). We reported previously that older adults did not experience appreciable declines in emotion discrimination, in the context of a different response inhibition task (Go/No-go task; Waring et al., 2019). In the present investigation, participants needed to distinguish between three types of expressions that differed substantially in their valence, (i.e., considering "Is this a fear face, happy face, or neutral face?"). Participants did not need to distinguish between more subtle and challenging facial expression distinctions that more often reveal age differences, such as fear versus sadness (Schel & Crone, 2013; Tottenham et al., 2011). Additionally, the brain areas supporting responses to emotional information, such as amygdala, medial prefrontal cortex, and basal ganglia, are preserved in late life (Ebner et al., 2012) adding mechanistic support to behavioural evidence of preserved emotional discrimination with aging. To extend the literature on this topic, future studies could also investigate how using images of emotional and neutral faces that are age-matched to participants may influence emotional response inhibition across age groups.

Several future directions could also be explored to inform effects of aging on emotional response inhibition. The present studies measured only reactive response inhibition and one type of task-relevance per participant. Future studies could utilize a within-subjects design to permit direct comparison between effects of proactive and reactive stopping, and effects of task-relevant versus task-irrelevant emotional stimuli. Varying the stop-signal task instructions within-person may offer more insight into how task-relevant versus task-irrelevant emotional stimuli can impact emotional response inhibition. Future studies could also investigate how presenting an emotional stimulus prior to a neutral, arbitrary stop-signal, such as a particular shape or sound, could offer insight into alterations of response inhibition differently in younger versus older adults. Eye-tracking could measure how visual attention contributes to the observed results, and whether it differs by age group. Event-related EEG or fMRI techniques could offer mechanistic insights into inconsistencies in the younger adults behavioural literature and illuminate interactive effects of emotion and cognitive aging on the observed behavioural results.

Conclusion

This is the first publication to investigate whether reactive emotional response inhibition changes with aging, and systematically test if effects differ based on task instructions (e.g., focus on emotion is task-relevant versus task-irrelevant). We demonstrated that manipulating task instructions across three behavioural studies in younger and older adults induces different patterns of emotional response inhibition. Emotion impacted response inhibition only when participant focus was directed to emotional attributes of facial expressions. When directly comparing happy faces to fear faces, happy face facilitated response inhibition in both younger and older adults, yet other effects differed by age group. Happy faces additionally enhanced response inhibition relative to neutral faces in older adults (but not younger adults). Thus, this series of studies demonstrates that emotional response inhibition for task-relevant, positive information is enhanced in late life compared to early adulthood. The present work extends the nascent literature on emotional response inhibition in aging, and also proffers a framework to reconcile the mixed literature on this topic in younger adults.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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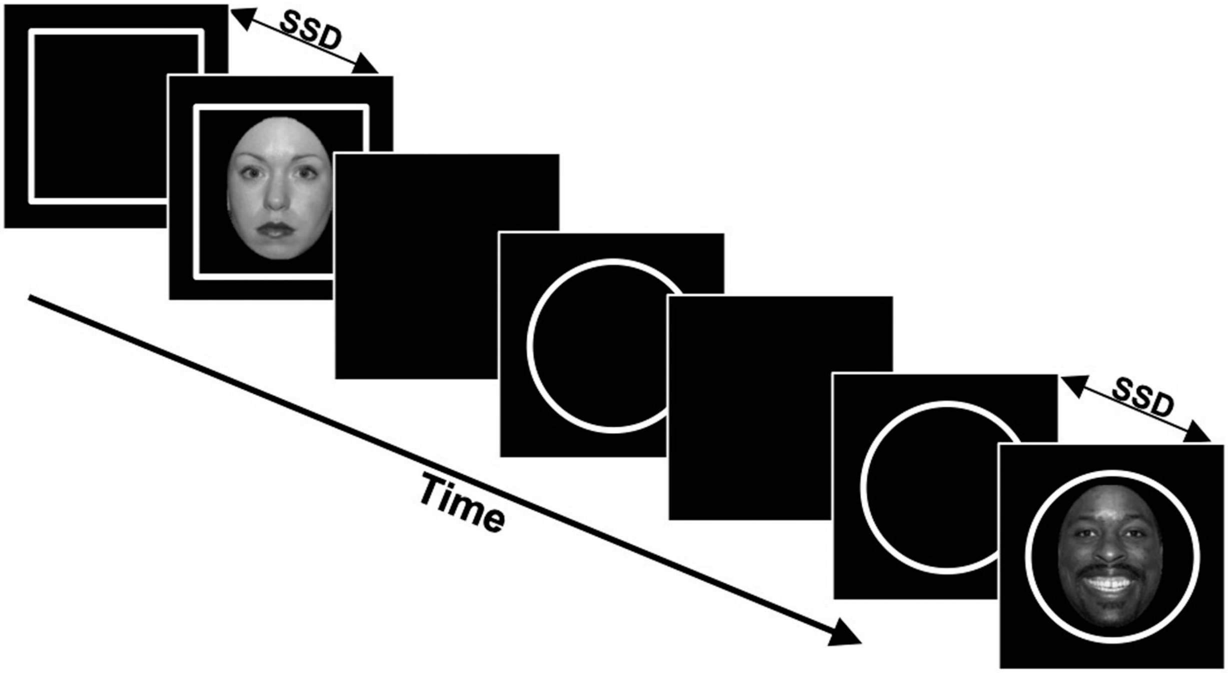

Fig. 1. Stop-Signal Task Schematic for Studies 1, 2, and 3

During go trials (e.g., no face appears inside the shape), participants responded to the go signal (circle or square), whereas during stop trials, they were instructed to withhold motor response. In Study 1 all faces signalled a stop trial, in Study 2, a specific gender (either male or female) signalled a stop trial, and in Study 3, a specific facial expression (fear, neutral, or happy expression) signalled a stop trial. The stop-signal followed the go stimulus after a variable-length delay, the stop-signal delay (SSD), which was independently adaptive for each stop-signal condition (e.g., fear, happy, or neutral facial expressions) to maintain behavioural performance at approximately 50% correct.

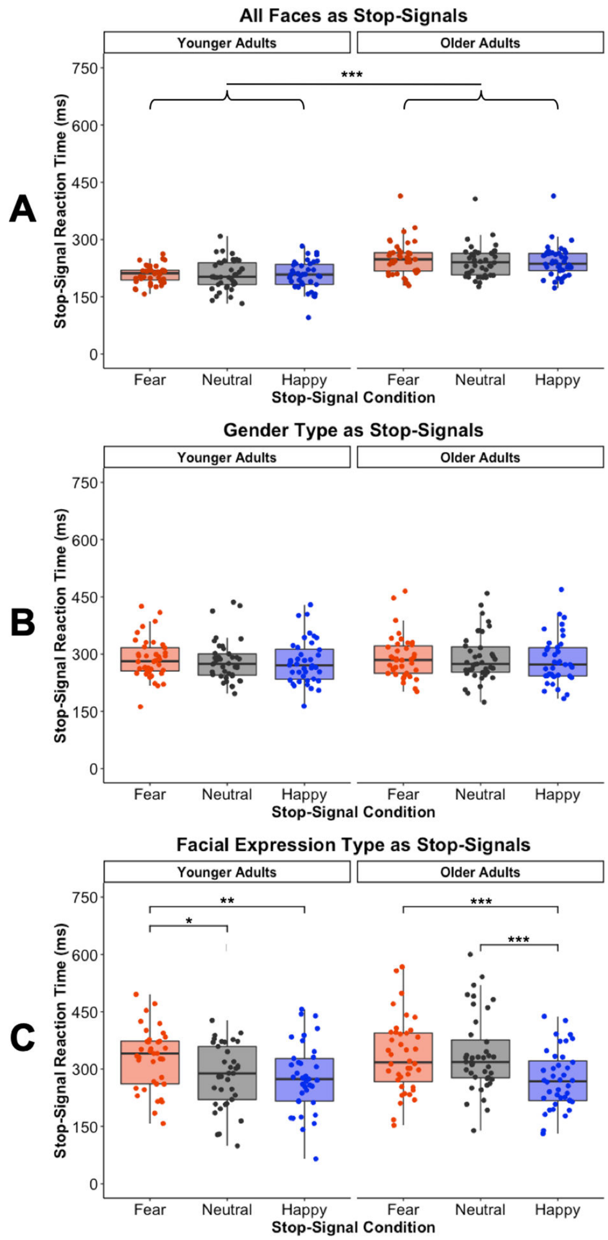

Fig. 2. Stop-Signal Reaction Time Results by Study, Age, and Stop-Signal Condition

A) Study 1 stop-signal reaction times when all faces indicated stop-signals. Younger adults were more efficient at stopping responses to all stop-signal conditions than older adults. B) Study 2 stop-signal reaction times when gender type indicated stop-signals. There were no effects of age or condition. C) Study 3 stop-signal reaction times when facial expression types indicated stop-signals. Younger adults were less efficient at stopping responses to fear faces compared to neutral faces, and older adults were more efficient at stopping responses to happy faces compared to neutral faces. Lower values represent more efficient response inhibition. Lower and upper box boundaries represent 25th and 75th percentile stop-signal reaction times values, respectively; line inside box represents median stop-signal reaction time values. * = $p < .05$; ** = $p \leq .01$; *** = $p < .001$

Table 1

Go Trial Descriptive Statistics from Studies 1, 2, and 3

Study Version	Age Group	Go RT (ms)	Go error rate (%)
Study 1	Younger Adults	652.40 ± 89.09	6.50 ± 4.73
	Older Adults	690.61 ± 93.94	7.51 ± 5.34
Study 2	Younger Adults	606.02 ± 91.89	8.30 ± 4.97
	Older Adults	636.48 ± 60.94	7.75 ± 5.56
Study 3	Younger Adults	593.44 ± 74.98	8.17 ± 6.89
	Older Adults	657.05 ± 70.16	8.64 ± 5.46

Note. Go RT = mean ± standard deviation of median response times to go trials;

Go error rate = mean ± standard deviation of mean percentage of missed go trials.

Table 2

Stop Trial Descriptive Statistics from Studies 1, 2, and 3

Study Version	Age Group	Stop-Signal Condition	Inhibition Rate (%)	Stop-Signal Delay (ms)	Stop-Signal Reaction Time (ms)	Unsuccessful RT (ms)
Study 1	Younger Adults	Fear	54.91 ± 2.32	443.70 ± 96.98	208.70 ± 23.77	591.99 ± 92.17
		Neutral	54.68 ± 2.34	444.94 ± 106.10	207.46 ± 39.30	602.20 ± 96.89
		Happy	55.26 ± 2.44	446.55 ± 99.10	205.85 ± 38.05	598.68 ± 94.53
	Older Adults	Fear	53.53 ± 8.78	441.47 ± 108.95	249.14 ± 44.34	631.50 ± 90.23
		Neutral	54.09 ± 8.22	449.17 ± 111.07	241.43 ± 41.45	638.01 ± 97.16
		Happy	53.83 ± 8.63	449.17 ± 112.65	241.43 ± 41.47	639.20 ± 94.40
Study 2	Younger Adults	Fear	51.28 ± 5.78	318.08 ± 123.88	287.94 ± 53.15	601.34 ± 80.71
		Neutral	51.31 ± 5.01	324.20 ± 121.61	281.82 ± 54.61	593.80 ± 75.62
		Happy	51.20 ± 5.70	326.93 ± 122.76	279.09 ± 57.88	595.99 ± 76.98
	Older Adults	Fear	52.09 ± 7.53	345.89 ± 103.02	290.59 ± 57.00	631.77 ± 49.90
		Neutral	51.63 ± 7.71	345.86 ± 104.87	290.62 ± 63.17	629.44 ± 51.92
		Happy	52.66 ± 8.26	351.16 ± 107.25	285.32 ± 63.06	631.09 ± 57.82
Study 3	Younger Adults	Fear	52.07 ± 5.98	265.39 ± 119.03	328.05 ± 80.34	630.39 ± 59.89
		Neutral	53.83 ± 7.46	311.53 ± 129.39	281.91 ± 82.91	613.76 ± 74.91
		Happy	51.22 ± 7.00	315.09 ± 119.41	278.35 ± 89.38	610.92 ± 62.02
	Older Adults	Fear	53.54 ± 3.09	323.54 ± 115.01	333.51 ± 96.09	653.98 ± 64.94
		Neutral	51.71 ± 5.57	318.81 ± 126.46	338.24 ± 101.61	657.47 ± 86.18
		Happy	54.62 ± 4.28	384.27 ± 110.48	272.78 ± 76.71	654.63 ± 69.52

Note. All values represent mean ± standard deviation; Unsuccessful RT = response times for stop trials to which participants responded.