Influence of response prepotency strength, general working memory resources, and specific working memory load on the ability to inhibit predominant responses: A comparison of young and elderly participants.

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Abstract

One conception of inhibitory functioning suggests that the ability to successfully inhibit a predominant response depends mainly on the strength of that response, the general functioning of working memory processes, and the working memory demand of the task (Roberts, Hager, and Heron, 1994). The proposal that inhibition and functional working memory capacity interact was assessed in the present study using two motor inhibition tasks (Go/No-Go and response incompatibility) in young and older participants. The strength of prepotency was assessed with a short or long training phase for the response to be inhibited. The influence of working memory resources was evaluated by administering the tasks in full versus divided attention conditions. The effect of working memory load was manipulated by increasing the number of target and distracter items in each task. Results showed no effect of prepotency strength, whereas dividing attentional resources and increasing working memory load were associated with greater inhibitory effects in both groups and for both tasks. This deleterious effect was higher for older participants, except in the working memory load condition of the Go/No-Go task. These results suggest an interactive link between working memory and response inhibition by showing that taxing working memory resources increases the difficulty of inhibiting prepotent responses in younger and older subjects. The additional detrimental effect of these factors on healthy elderly subjects was related to their decreased cognitive resources and to their shorter span size.

Keywords: motor inhibition, aging, working memory

1. Introduction

Inhibitory functioning is a basic aspect of cognitive and emotional functioning involved in the performance of numerous tasks and processes; it is necessary to maintain an adequate level of adjustment to environmental demands (Bjorklund and Harnishfeger, 1995; Dagenbach and Carr, 1994; Dempster and Brainerd, 1995). Generally speaking, inhibition can be defined as the set of processes that allow one to suppress the production of a predominant but inappropriate response, prevent irrelevant information from entering consciousness, or suppress no longer relevant information from one's attentional focus.

It is now admitted that inhibition is not a unitary process; instead, it may encompass a large range of various cognitive processes. Indeed, weak or non-significant correlations between inhibitory tasks have frequently been observed (Charlot and Feyereisen, 2005; Collette et al., 2007; Kramer, Humphrey, Larish, Logan, and Strayer, 1994; Rush, Barch, and Braver, 2006; Shuster and Toplak, 2009; Witthöft, Sander, Süb, and Wittmann, 2009), and several studies have reported selective inhibitory deficits in different pathological conditions (Amieva, Phillips, Della Sala, and Henry, 2004; Collette et al., 2007; Conway and Fthenaki, 2003). Consequently, different theoretical frameworks have emerged in an attempt to classify inhibitory abilities. For example, Hasher and Zacks (e.g., Hasher, Zacks, and May, 1999) related inhibition to working memory and described three general inhibitory functions: access, deletion, and restraint. Another theoretical framework was formulated by Harnishfeger (1995), who suggested dissociating intentional from unintentional inhibitory processes (for a similar proposal, see Nigg, 2000). A different approach was proposed by Dempster and Corkill (1999a, 1999b), who distinguished developmentally and functionally distinct inhibitory processes in the perceptual, motor, and verbal domains. Finally, Friedman and Miyake (2004) differentiated between inhibitory processes according to the internal/external nature of the stimulus to be suppressed.

Deficits in inhibitory abilities have been proposed as one of the causes of the diminished daily functioning that characterizes normal aging (e.g., Harnishfeger, 1995; Harnishfeger and Bjorklund, 1993). Indeed, cognitive aging has been associated with a decline in inhibitory abilities, as tested with a wide variety of tasks and procedures, such as the Stroop task (e.g., Bélanger, Belleville, and Gauthier., 2010; Bugg, DeLosh, Davalos, and Davis, 2007), negative priming task (e.g., Kane, Hasher, Stoltzfus, Zacks, and Connelly, 1994; Verhaegen and De Meersman, 1998), Hayling task (e.g., Bélanger and Belleville, 2009; Belleville, Rouleau, and Van der Linden, 2006), stop-signal and Go/No-Go procedures (e.g., May and Hasher, 1998; Nielson et al., 2004), antisaccade task (e.g., Nelles, de Greiff, Pscherer, and Esser, 2009; Peltsch, Hemraj, Garcia, and Munoz, in press) and response incompatibility tasks (e.g., Castel, Balota, Hutchison, Logan, and Yap, 2007; Juncos-Rabadán, Pereiro, and Facal, 2008). However, normal performance was also sometimes observed on these tasks (e.g., Hogge, Salmon, and Collette, 2008; Little and Hartley, 2000, for the negative priming and Stroop tasks; Kubo-Kawai and Kawai, 2010; Rush et al., 2006, for response incompatibility and Go/No-Go tasks).

Interestingly, when batteries of tasks developed on the basis of current taxonomies of inhibition are administered to young and older participants, specific inhibitory impairments that support the theoretical proposals are observed. Charlot and Feyereisen (2004, 2005) explored the access, deletion and restraint functions of inhibition associated with working memory (Hasher et al., 1999) and observed that the effects of aging are less pronounced on the access function than on the deletion and restraint functions (see, however, Dumas and Hartman, 2008, who found no evidence of any age effect on the access and deletion functions). With regard to the distinction between intentional/controlled and unintentional/automatic inhibitory processes proposed by Harnishfeger (1995) and Nigg (2000), a dissociation was observed, with decreased performance on tasks requiring intentional/controlled inhibitory processes but preserved unintentional/automatic inhibitory abilities (Andrés, Guerrini, Philips, and Perfect, 2008; Collette, Germain, Hogge, and Van der Linden, 2009; Collette, Schmidt, Scherrer, Adam, and Salmon, 2009).

A common characteristic of most of the studies of inhibitory functioning in normal aging is that they consider inhibition from a qualitative viewpoint only. In other words, the aim of these studies was to disentangle inhibitory processes (e.g., to distinguish between inhibitory functions in working memory or between controlled and automatic inhibitory processes) and to determine whether specific deficits affect processes considered to be qualitatively different (e.g., motor and perceptual inhibition). A complementary (more quantitative) approach to inhibitory functioning would be to take into account the impact of task and material characteristics that must be inhibited during performance. In that regard, the proposal by Houghton and Tipper (1994) sounds particularly interesting. These authors claimed that “the strength of the inhibition continually adapts to the strength of the to-be-ignored inputs” (p. 107). In other words, the inhibition required to suppress a cognitive operation (or content) that is irrelevant for the ongoing task will be more effortful and resource-demanding for highly activated cognitive operations or contents. According to this proposal, the efficiency of inhibitory functioning depends directly on the amount of resources available to suppress the irrelevant activated contents or processes.

In agreement with this proposal, Roberts et al. (1994; see also Roberts and Pennington, 1996) developed the assumption that there is an interactive link between functional working memory capacity and inhibitory efficiency. In these authors’ view, the successful inhibition of one predominant response requires participants to keep in mind all the information and instructions that permit them to perform the task appropriately by avoiding prepotent responses and promoting correct responses. From their point of view, task performance is thus clearly dependent on (1) the strength of the prepotency of the response to be inhibited, (2) the current functioning of working memory processes, and (3) the task's working memory demand. These characteristics can be considered as independent, in the sense that some tasks involve a highly predominant response (built-in or previously acquired) associated with little working memory demand (e.g., the antisaccade task) whereas others make more demand on working memory but have no preexisting prepotency (e.g., the Wisconsin Card Sorting Test, in which prepotency is only established after several trials within the task). In support of their proposal, Roberts et al. showed that the administration of an antisaccade inhibitory task simultaneously with an addition solving task led to poorer inhibitory performance (i.e., presence of more reflexive saccades and slower antisaccades) by comparison to the administration of the antisaccade task alone or in association with a less-demanding secondary task (digit repetition). As a whole, these results indicate that the main determinant of decreased inhibitory abilities is the working memory demand associated with the secondary task, but not the requirement to perform two tasks simultaneously. This deleterious effect of decreased resource availability on saccadic performance was confirmed in subsequent studies (Eenshuistra, Ridderinkhof, and van der Molen, 2004; Mitchell, Macrae, and Gilchrist, 2002; Stuyven, Van der Goten, Vandierendonck, Claeys, and Crevits, 2000).

Other data supporting the idea of a functional link between working memory capacity and inhibitory efficiency come from studies comparing inhibitory performance in participants with high or low working memory resources, as assessed by span size. For example, Kane, Bleckley, Conway, and Engle (2001) showed that participants with low span size were slower and less accurate than high-span participants on an antisaccade task (see also Unsworth, Schrock, and Engle, 2004). Similar results have been found for the Stroop task (Kane and Engle, 2003), the dichotic-listening task (Conway, Cowan, and Bunting, 2001), the directed forgetting paradigm (Aslan, Zellner, and Bäuml, 2010), or the Go/No-Go task (Redick, Calvo, Gay, and Engle, 2011).

Lustig, May, and Hasher (2001) have also observed a relationship between working memory span size and sensitivity to proactive interference: lower-span participants found it more difficult to deal with proactive interference than higher-span participants. Interestingly, similar results were observed when working memory capacity was assessed using a more attentionally demanding dichotic-listening paradigm (Colflesh and Conway, 2007): individuals with higher working memory capacity were more efficient at detecting and responding to their own name presented in the irrelevant message while continuing to perform the classic dichotic-listening task. Similarly, negative effects of working memory load on inhibitory control have also been found in other paradigms such as visual selective attention (De Fockert, Rees, Frith, and Lavie, 2001; Lavie, Hirst, De Fockert, and Viding, 2004) and Go/No-Go (Hester and Garavan, 2005; Redick et al., 2011).

At this time, few data exist concerning the influence of the availability of working memory resources on inhibitory functioning in normal aging. Eenshuistra et al. (2004) administered an antisaccade task to young and older participants, both alone and in association with a working memory updating task. As expected, increased antisaccade latencies were observed in both groups of participants when they were simultaneously performing the concurrent working memory task. Moreover, older adults produced more reflexive saccades than younger ones when performing the two tasks simultaneously.

1.1. Overview of the study

Previous studies of the relationship between functional working memory capacity and inhibitory efficiency, as formulated by Roberts et al. (1994), explored the effect of decreased resource availability on young participants (e.g., Mitchell et al., 2002; Roberts et al., 1994; see, however, Eenshuistra et al., 2004, for data on normal aging). Consequently, in the present study, we were interested in exploring, in a single sample of younger and older participants, (1) the effect on inhibitory efficiency of the three working-memory-related factors proposed by Roberts et al.; and (2) the effect of normal aging on the relationship between working memory capacity and inhibitory abilities.

In order to determine the generality of the effects observed, we administered to participants two motor inhibitory tasks (Go/No-Go and response incompatibility) in which response prepotency, resource availability in working memory and task-specific working memory load were varied. According to Roberts et al. (1994), maintaining task-relevant information in an active state in working memory is more effortful in situations of high than of low prepotency. So response prepotency was manipulated by administering short or long habituation phases during which the response to be inhibited was trained and reinforced. To determine the effect of working memory resource availability, a classical dual-task paradigm was administered in which the inhibitory tasks were performed in isolation or concurrently with an arithmetic task. Finally, the effect of increased task-specific working memory load was assessed by comparing performance on versions of the inhibitory tasks that require subjects to maintain different amounts of task-relevant information in working memory.

Our predictions were that a decrease in inhibitory efficiency should be observed in the conditions where the response to be inhibited was reinforced (high prepotency), where few working memory resources were available (divided attention condition), and where there was a higher memory load (conditions requiring subjects to maintain more task-related information). With regard to normal aging, a general decrease in inhibitory functioning was expected (Juncos-Rabadán et al., 2008; Nielson et al., 2004). We also predicted that response prepotency, decreased resource availability and increased task-specific working memory load would have a stronger negative effect in older subjects. Indeed, normal aging is associated with difficulties suppressing an irrelevant but highly activated response, as in the Hayling task (e.g., Belleville et al., 2006). It is also widely acknowledged that the cognitive resources available to perform mental operations decline with aging (Park and Hedden, 2001). Consequently, older subjects should have fewer resources available to initiate efficient inhibitory processes in divided attention situations or when the task requires them to maintain a large amount of information in working memory.

2. Methods

2.1. Participants

A total of 60 young (range: 18–30 years, M = 23.17; SD = 2.87; 28 females and 32 males) and 60 older (range: 64–81 years, M = 71.22; SD = 4.66; 30 females and 30 males) participants took part in the experiment. The study was approved by the Ethics Committee of the Faculty of Psychology of the University of Liège, and was performed in accordance with the ethical standards described in the Declaration of Helsinki (1964). All participants were native French speakers and naive about the purpose of the experiment. The older participants had normal or corrected-to-normal vision and hearing, and reported no history of medical, neurological or psychiatric disorders. Moreover, they were not using any medications that could affect their performance on the different experimental tasks. Finally, their cognitive status was checked by administering the Mattis Dementia Rating Scale (Mattis, 1976). All the elderly participants had a total score equal to or greater than 130 (range 130–144), which constitutes the cut-off score to distinguish between normal aging and dementia (Monsch et al., 1995). The young and older groups of participants differed in terms of education level (level of education: young participants: M = 15.02 years; SD = 2.31; elderly participants: M = 12.78 years; SD = 5; t (118) = -3.14; p = .002) and in terms of vocabulary level on the French adaptation of the Mill Hill test (Deltour, 1993; young participants: M = 23.43; SD = 4.13; elderly participants: M = 24.7; SD = 6.65; t (118) = 1.25; p = .21).

2.2. Materials and procedure

The participants were tested individually in a quiet, well-lighted room. Each participant was seen four times, once a week during four weeks, with a maximum duration of 90 minutes per session. The Go/No-Go and conflict resolution tasks were presented on a microcomputer with a 15-inch color monitor using E-Prime software version 1.1 Service pack 3 (Schneider, Eschman, and Zuccolotto, 2002). Participants were seated in front of the computer screen so that their eyes were approximately 50 cm from the display. All response keys were located on a standard AZERTY keyboard.

The order of task administration was counterbalanced across participants such that half of the participants always performed the Go/No-Go before the conflict resolution task and the other half performed them in the reverse order. Moreover, participants who performed the "high-prepotency" condition of the Go/No-Go task performed the "low-prepotency" condition of the conflict resolution task and vice versa. Finally, the three evaluation sessions (one for prepotency strength, one for divided attentional resources, and one for increased working memory load specific to the task) were separated by one week and the testing for a given participant took place at the same time of day for each session.

2.3. Tasks

2.3.1. Go/No-Go task

The Go/No-Go task, adapted from Zimmerman and Fimm (1994), was composed of two conditions. In the first condition, two three-dimensional colored figures were presented to the participant. The task here was to respond as fast and accurately as possible by pressing a response key each time a figure appeared on the screen. Stimuli were presented for 2 seconds or until the subject responded. This first condition was composed of 40 items separated by a white screen of variable duration (400, 800, 1200, or 1600 msec). The second condition comprised 120 items. In this phase, the two target stimuli from phase 1 and three new figures were presented pseudo-randomly. The participant's task was again to respond as fast and accurately as possible to the two stimuli presented in phase 1 but not to the three new figures. Two-thirds of the trials were "Go" trials (80 items) and one-third were "No-Go" trials (40). The "Go/No-Go effect" was evaluated by comparing (1) performance on items in the simple reaction time condition with "Go" trials of the "Go/No-Go" condition, and (2) accuracy for "No-Go" trials.

Prepotency strength was manipulated by administering the task with 80 trials instead of 40 in the first condition. Doubling the items in the first condition was expected to reinforce the automaticity of the response to be inhibited. The general working memory resources effect was assessed by administering the task in a divided attention condition, in which participants concurrently performed simple additions of two digits between 1 and 9 each. Finally, the effect of working memory load specific to the task was assessed by administering the task with an increased number of target and distracter items. More specifically, three targets were presented in the first condition (instead of two) and four distracters (instead of three) in the Go/No-Go condition.

2.3.2. Motor conflict task

This task was adapted from Nassauer and Halperin (2003) and was also composed of two conditions. As in the Go/No-Go task, the first condition involved 40 items in which a white rectangular box was presented pseudo-randomly on the right (20 trials) or left (20 trials) side of the screen. Each stimulus was presented for 3 seconds or until the participant responded, and was preceded by a fixation cross for 1 second. Participants were asked to press the key located on the same side as the rectangle as fast and accurately as possible. As in the Go/No-Go task, the purpose of this habituation phase was to elicit a tendency to respond in agreement with the stimulus location. In the second condition, the instructions changed, and the participants had to respond by pressing the key located on the opposite side from the rectangle. There were a total of 120 trials (60 trials with the rectangle appearing on the left and 60 on the right). The motor conflict effect was assessed by comparing performance between the two conditions, with slower and less accurate responses expected in the second condition, in which motor inhibition is required.

As in the Go/No-Go task, prepotency strength was manipulated by administering the task with 80 trials in place of 40 in the first condition, and the general working memory resource effect was assessed by administering the task in a divided attention condition with the simultaneous execution of an addition task. The effect of task-specific working memory load was assessed by increasing the number of stimulus locations. In fact, in the high-working-memory-load condition, the rectangle appeared not only on the left and right sides but also at the top and bottom of the screen. The instructions were therefore quite different in that condition. During the habituation phase, subjects were instructed to press a top left button on the keyboard each time the rectangle appeared on the left or at the top of the screen and a bottom right button each time it appeared on the right or at the bottom of the screen. During the test phase, these responses were reversed, and the subjects had to press the top left key for each stimulus presented on the right or at the bottom and conversely for the bottom right key.

2.3.3. Short-term memory tasks

Since one major focus of this study was the link between working memory functioning and inhibitory functioning, we administered forward and backward digit span tasks to assess working memory in both groups of participants and the possible contribution of a reduction in short-term memory functioning on our inhibitory tasks. In the forward digit span task, lists of two to nine digits were read by the examiner at the rate of one digit per second, and the subject had to recall the sequence immediately afterwards. Three sequences of each length were presented until the subject failed at three sequences with a given length. The longest sequence correctly recalled on at least two of the three trials constituted the subject's digit span. The only difference in the backward digit span task is that the subjects must recall the sequence beginning with the last digit and working backward to the first one. Whereas the forward condition involves storing information in working memory, the backward condition involves both storing and manipulating information in working memory.

2.3.4. Processing speed task

We used a choice reaction time task to assess general processing speed. This task was a letter comparison task, which is a computerized version of the task initially proposed by Salthouse and Babcock (1991). The participants had to press one button if two letters presented on the screen were the same and another button if they were different. They were told to perform the task as fast and accurately as possible. The test was composed of 60 items (30 "same letters" and 30 "different letters"). For the analysis, we used only the mean reaction times for the "same letter" items that were correctly responded to. The major interest of this task is the absence of distraction from task-irrelevant information, which could alter participants' performance, especially in elderly subjects (Lustig, Hasher, and Tonev, 2006).

3. Results

An alpha level of .05 was used for all statistical analyses. Given that this significance test is highly dependent on the size of our sample; we also used partial eta squared (for each main effect and interaction) as an estimate of the magnitude of the effect that was relatively independent of sample size. Each value for a factor (main effect or interaction) presented hereafter can be interpreted as the percentage of variability not explained by other factors.

Factorial and repeated measures ANOVAs were performed for each task individually. The effect of prepotency manipulation on accuracy was investigated with a factorial ANOVA with group of participants (young vs. elderly participants) and condition (low vs. high prepotency) as the independent variables. All other differences in reaction times and in accuracy for the two groups between the different test phases and conditions were assessed using repeated measures ANOVAs, with test phase (habituation vs. inhibitory) or condition (full vs. divided attention/low vs. high working memory load) as repeated measures factor. Moreover, when significant effects were observed, we also performed planned comparisons in order to better specify the pattern of observed results ($p < .05$).

3.1. Prepotency strength effect

3.1.1. Go/No-Go task

A repeated measures ANOVA on mean reaction times showed a main effect of group [F (1, 116) = 77.78; $p < .0001$, $\eta_P^2 = .40$], with older adults responding slower overall than younger ones; a main effect of inhibition [F (1, 116) = 590.54; $p < .0001$, $\eta_P^2 = .84$], with slower reaction times during the test phase than the habituation phase; but no main effect of prepotency strength [F (1, 116) = 1.25; $p = .27$, $\eta_P^2 = .01$]. Moreover, none of the interactions were significant. The inhibitory effect associated with our Go/No-Go task seems therefore equivalent in both groups of participants, and we failed to show any effect of prepotency strength (see Figure 1a).

INSERT FIGURE 1 HERE

Mean numbers of errors are presented in Table 1a; they were analyzed with a factorial ANOVA. There exists no main effect of prepotency strength [F (1, 116) = .78; $p = .38$, $\eta_P^2 = .01$]. A main effect of group was observed, with more errors for younger than older adults [F (1, 116) = 6.56; $p = .01$, $\eta_P^2 = .05$], but the interaction was not significant.

INSERT TABLE 1 HERE

3.1.2. Conflict resolution task

A repeated measures ANOVA on mean reaction times showed main effects of group [F (1, 116) = 206.03; p < .0001, η_P^2= .64] and inhibition [F (1, 116) = 336.05; p < .0001, η_P^2= .74], but still no prepotency effect [F (1, 116) = .04; p = .84, η_P^2< .001]. None of the interactions was significant, except for the interaction between group and inhibition [F (1, 116) = 46.88; p < .0001, η_P^2= .29], indicating that the increase in reaction times from the habituation to the inhibition condition was greater for older than younger adults (Figure 1b).

With regard to accuracy (see Table 1a), the factorial ANOVA revealed a main effect of group [F (1, 116) = 9.93; p = .002, η_P^2= .08], with older adults being more error-prone than younger ones, but once again there was no main effect of prepotency strength and no significant interaction.

3.2. Influence of general working memory resources

3.2.1. Go/No-Go task

A repeated measures ANOVA on mean reaction times for the Go/No-Go task revealed a main effect of group [F (1, 116) = 79.85; p < .0001, η_P^2= .41], with older adults being slower than younger ones; a main effect of condition [F (1, 116) = 159; p < .0001, η_P^2= .58], with longer reaction times in the divided attention condition; and a significant interaction between group and condition [F (1, 116) = 10.97; p = .001, η_P^2= .09] (see Figure 2a). Planned comparisons showed greater slowing for older [F (1, 116) = 126.74; p < .0001] than younger adults [F (1, 116) = 43.23; p = .0001] when performing the divided attention condition.

INSERT FIGURE 2 HERE

A repeated measures ANOVA on response accuracy revealed the same pattern of results, with a main effect of group [F (1, 116) = 13.76; p < .001, η_P^2= .11], and of condition [F (1, 116) = 75.60; p < .0001, η_P^2= .39], and a significant interaction between group and condition [F (1, 116) = 28.15; p < .0001, η_P^2= .20] (see Table 1b). Planned comparisons showed that older adults produced fewer errors than younger ones in the full attention condition [F (1, 116) = 6.56; p = .01], but more errors than younger adults in the divided attention condition [F (1, 116) = 21.80; p < .0001].

3.2.2. Conflict resolution task

As with the Go/No-Go task, a repeated measures ANOVA on mean reaction times showed a main effect of group [F (1, 116) = 188.02; p < .0001, η_P^2= .62], and of condition [F (1, 116) = 162.90; p < .0001, η_P^2= .58], and a significant interaction between group and condition [F (1, 116) = 36; p < .0001, η_P^2= .24]. Once again, the deleterious effect of divided attention was more pronounced for older than younger adults (Figure 2b).

The pattern of results concerning accuracy data (Table 1b) is similar to that observed for mean reaction times, with a main effect of group [F (1, 116) = 27.72; p < .0001, η_P^2= .19], and of condition [F (1, 116) = 40.91; p < .0001, η_P^2= .26], and a significant interaction [F (1, 116) = 17.91; p < .0001, η_P^2= .13].

3.3. Influence of task-specific working memory load

3.3.1. Go/No-Go task

A repeated measures ANOVA on mean reaction times showed a main effect of group [F (1, 116) = 84.51; p < .0001, η_P^2= .42] and condition [F (1, 116) = 24.78; p < .0001, η_P^2= .18], but no interaction between these factors [F (1, 116) = .47; p = .49, η_P^2< .01], indicating that the high-working-memory-load condition (complex version including more target and distracter items) increased reaction times in a similar way in both groups of participants (see Figure 3a).

INSERT FIGURE 3 HERE

Accuracy data for the high-working-memory-load condition are presented in Table 1c. A repeated measures ANOVA revealed an interaction between group and condition [F (1, 116) = 5.29; p = .02, η_P^2= .04], but no main effect of group [F (1, 116) = .004; p = .95, η_P^2<.0001] or condition [F (1, 116) = 2.84; p = .09, η_P^2=.02]. Planned comparisons showed that older adults made more errors on the complex version of the task than on the standard version [F (1, 116) = 7.95; p = .006]. However, since younger adults made more errors than older ones on the standard version [F (1, 116) = 6.56; p = .01], the numbers of errors for older and younger adults on the complex version of the task did not differ [F (1, 116) = 1.4; p = .24].

3.3.2. Conflict resolution task

A repeated measures ANOVA on mean reaction times showed a main effect of group [F (1, 116) = 265.24; p < .0001, η_P^2= .70], a main effect of condition [F (1, 116) = 192.30; p < .0001, η_P^2= .62], and a significant interaction between these factors [F (1, 116) = 41.88; p < .0001, η_P^2= .27]. Planned comparisons indicated that reaction times were more slowed for older adults during the high-working-memory-load condition of the task (see Figure 3b).

Accuracy data analyses confirmed these results, showing a main effect of group [F (1, 116) = 37.82; p < .0001, η_P^2= .25], and condition [F (1, 116) = 73.36; p < .0001, η_P^2= .39], as well as an interaction effect [F (1, 116) = 23.24; p < .0001, η_P^2= .17]. Planned comparisons indicated that the increase in errors rate in the high-load condition was greater for older adults than for younger adults (see Table 1c).

3.4. Short-term memory and speed of processing tasks

As expected, we found significant differences between our two groups of participants for the two digit span tasks [t (118) = –3.68; $p < .001$ and t (118) = –5.58; $p < .0001$, for the forward and backward conditions, respectively], and the processing speed task [t (118) = 12; $p < .0001$]. Means and standard deviations are presented in Table 2.

INSERT TABLE 2 HERE

3.5. Correlation analysis

Correlations between working memory span and inhibitory task measures were performed for each group to further explore the relationships between working memory and inhibitory functioning. The only correlations found for younger adults were between backward span and reaction times in the habituation phase of the Go/No-Go and motor conflict task (r = – .27, $p <$ .05 for Go/No-Go; r = –.29, $p < .05$ for conflict resolution). In the older adult group, we found that forward span correlated significantly with reaction times and accuracy in the test phase of the Go/No-Go complex version (respectively, r = –.30, $p < .05$; and r = –.26, $p < .05$), and with reaction times in the test phase of the standard version of the motor conflict task (r = –.36, $p <$ .01). Moreover, backward span also correlated with reaction times in the Go/No-Go (in the habituation phase: r = –.27, $p < .05$; in the test phase of the divided attention condition: r = –.29, $p < .05$; and in the test phase of the complex version: r = –.32, $p < .05$) and with the motor conflict task (reaction times in the standard test phase: r = –.31, $p < .05$; accuracy in the standard test phase: r = –.29, $p < .05$; and accuracy in the divided attention condition: r = –.26, $p < .05$).

Processing speed correlated with all the reaction time measures of the habituation and inhibition conditions of both tasks for both young and older adults (all ps < .05), except for reaction times in the divided attention condition of the motor conflict task in the young participants. The pattern was somewhat more mixed for accuracy data, with significant correlations between response times and a majority of measures on the Go/No-Go task (all *p*s < .05, except for accuracy in divided attention in younger adults and for accuracy in the standard condition for older adults, where the correlations were not significant), but none with the motor conflict task (all *p*s >.05). Moreover, correlations between accuracy measures and processing speed were positive in older participants (indicating that slower response times are associated with more errors) but negative in younger participants (indicating that slower response times are associated with fewer errors).

4. Discussion

In this study, we wished to investigate the interaction of inhibitory functioning and working memory capacity, based primarily on the proposal of Roberts et al., who had linked these two abilities (Roberts et al., 1994; Roberts and Pennington, 1996). Consequently, we assessed the performance of young and elderly participants on two motor inhibitory tasks (a Go/No-Go task and a motor conflict resolution task), while varying the prepotency strength of the response to be inhibited, the availability of working memory resources, and the working memory demand of the task.

The classical inhibitory effects were observed for the basic versions (namely, in the condition of low prepotency, full attention and low task-related memory load) of both tasks and for both groups of participants, with an increase in response times from the practice to the test phase. However, a specific age effect on inhibitory abilities was found for the conflict resolution task only; there was no group difference for the Go/No-Go task. In that task, older adults were slower than younger ones in both the habituation and inhibition conditions, but the inhibitory effect was similar in the two groups.

One possible explanation of the absence of aging effect for the Go/No-Go task is related to the nature of the task. More specifically, the characteristics of the task itself could explain the lack of any group difference. Indeed, the presence of an age-related impairment affecting the Go/No-Go procedure has not been systematically reported in the literature (e.g., Falkenstein, Hoormann, and Hohnsbein, 2002; Rush et al., 2006), and the absence of deficit could be attributed to the fact that the Go/No-Go paradigm is a relatively easy task requiring few cognitive resources (in the present experiment, only one stimulus-response mapping was needed and there was no conflict between perceptual and motor processes involved in the task). The studies by Nielson and colleagues (Nielson, Langenecker, and Garavan, 2002; Nielson et al., 2004) that found evidence of motor inhibitory difficulties in aging used a much more resource-demanding Go/No-Go paradigm, with very briefly presented items, no interstimulus interval, and more complex instructions requiring greater working memory involvement. Nevertheless, the presence in our older participants of impaired inhibitory performance in the conflict resolution task but not in the Go/No-Go task is particularly interesting. Indeed, it allows us to explore the effect of normal aging on the relationship between functional working memory capacity and inhibitory efficiency depending on whether the initial inhibitory performance is affected or not.

A summary of the results obtained in our different task conditions is presented in Table 3. These results indicate, for both the Go/No-Go and response conflict tasks, an effect of divided attentional resources and increased task-specific working memory load on inhibitory abilities, but no effect of response prepotency. Moreover, decreasing available working memory resources is more detrimental to the inhibitory abilities of older than of younger participants in both the Go/No-Go and conflict resolution tasks, while increasing task-related working memory requirements has a deleterious effect for older adults only in the conflict resolution task. These results are discussed in detail in the following sections.

INSERT TABLE 3 HERE

4.1. No effect of response prepotency

Contrary to the proposal made by Roberts et al. (1994), no response prepotency effect was observed on performance in the two inhibitory tasks. A likely explanation concerns the initial prepotency strength of the tasks used. In both tasks, the stimulus-response association is relatively simple and can thus be rapidly learned and easily practiced. Indeed, both tasks involve a reflex-like initial response (pressing the key each time a stimulus appeared or pressing the key corresponding to the stimulus location) and a relatively easy instruction with a low working memory demand (ceasing to respond when certain stimuli appeared or pressing the key in the opposite location from the stimulus). Thus, it is possible that prepotency was already at its highest level in the low-prepotency condition (40 items), and thus the presentation of more items in the longer practice session had absolutely no effect. Roberts et al. (1994) consider that manipulating prepotency in tasks that already have strong stimulus-response associations prior to the experiment is relatively difficult; instead, they suggest manipulating prepotency using tasks with no preexisting stimulus-response associations such as executive tasks with more complex rules and instructions (such as the Tower of Hanoi, Welsh, Satterlee, Cartmell, and Stine, 1999, or the Wisconsin Card Sorting Test, Rhodes, 2004). These tasks often make more demands on working memory (more complex instructions to maintain in memory, with specific rules to respect) but present little or no initial response prepotency. Rather, in those tasks, prepotency is progressively acquired. However, in that case, the inhibitory component is not very evident, and other processes seem to be engaged at least as much as inhibition (e.g., planning, rules deduction).

Although it may seem difficult, increasing or decreasing response prepotency in tasks with high initial automaticity is still possible. A good way of acting on prepotency strength is the Stroop task, in which color words written in different colors are presented (Stroop, 1935). Active goal maintenance in the face of competition from habit (name the color rather than read the word) has been the most frequently cited explanation of the classic Stroop effect (Cohen, Dunbar, and McClelland, 1990; Cohen, Servan-Schreiber, and McClelland, 1992). In these authors' opinion, the Stroop task requires participants to inhibit one overlearned response (read the words, typically conceived as very automatic since it is used in everyday life) in favor of a much less predominant response (name the colors, which is a much less frequently used process). Along the same lines, a good way to manipulate prepotency strength in this paradigm is to vary the proportion of congruent versus incongruent items. In fact, research has shown that the interference effect of incongruent items increases with the proportion of congruent trials in the experiment (Bélanger et al., 2010; Kane and Engle, 2003; Logan and Zbrodoff, 1979, 1998). Indeed, in the context of pure blocks of incongruent items, the inappropriate prepotent reading strategy is never reinforced, and it is therefore easier to perform such blocks than blocks containing an increasing proportion of congruent items in which goal maintenance abilities are more and more challenged. Interestingly, Bélanger et al. (2010) showed that congruency has a disproportionate effect in normal aging, finding more sensitivity to interference (as assessed by response times) when incongruent items are presented in blocks composed mainly of congruent items, as opposed to blocks composed mainly of non-congruent items. In other words, older people are more impaired when the prepotency strength of the response to be inhibited (e.g., reading the word) is highest.

Along those lines, modulating the proportion of the different types of items could be very useful in investigating prepotency, especially for motor conflict tasks such as those used in the present study. For example, in the Go/No-Go task, instead of comparing inhibitory performance following the stronger or weaker reinforcement of the response to inhibit, the prepotency effect could be explored by varying the proportion of go and no-go responses in the inhibitory condition. In that context, Mostofsky et al. (2003) proposed that the use of a ratio ≥ 3:1 (at least 3

Go trials for 1 No-Go trial) will increase the tendency towards a response for No-Go trials (see also Manly, Robertson, Galloway, and Hawkins, 1999; Nieuwenhuis, Yeung, van den Wildenberg, and Ridderinkhof, 2003, for the effect of trial type frequency on performance). Similarly, the introduction (in various proportions) of items that do not present a perceptual-motor conflict in the conflict resolution task should allow one to investigate the effect of response prepotency.

4.2. Effect of available working memory resources

Here, we were interested in replicating the results of previous studies that had shown less efficient inhibitory abilities when the availability of resources in working memory is decreased by asking participants to perform two tasks simultaneously (Castel, Pratt, and Craik, 2003; Mitchell et al., 2002). In our motor inhibitory tasks, the main working memory requirement consists in keeping the relevant instruction highly activated throughout the task, and particularly during the period in which the response is provided. Dividing attentional resources is supposed to create an insufficient level of activation, inducing slowed or erroneous responses. We were also interested in determining whether this effect is amplified in normal aging when a motor inhibitory task is used instead of an antisaccade task (Eenshuistra et al., 2004). As expected, we found that performing an arithmetic task simultaneously with the Go/No-Go and conflict resolution tasks affected the resources available for the primary task and impeded inhibitory functioning.

A detrimental effect of dividing attentional resources has frequently been reported in the literature for different cognitive abilities in young and in healthy elderly subjects, even with relatively easy tasks, such as the one-digit addition task used in our study (for a review, see Verhaegen, Steitz, Sliwinski, and Cerella, 2003). Moreover, the decrease in inhibitory performance from the full to the divided attention condition of the task was greater for older than younger adults, showing that the influence of resource availability on performance is magnified in aging. Importantly, this pattern of results seems not to depend on the initial inhibitory performance in the full attention condition of the tasks. Indeed, a deleterious age effect on inhibitory efficiency was observed when the availability of resources was decreased, in that the older adults presented initial inhibitory abilities similar to (Go/No-Go task) or somewhat lower (conflict resolution task) than those of younger participants. These results can be interpreted as reflecting a globally deleterious effect of dividing attentional resources, independently of initial inhibitory performance, rather than an accentuation of a preexisting inhibitory difficulty.

Consequently, the less efficient inhibitory functioning in normal aging observed here may be related to a decrease in the cognitive resources available in working memory. The hypothesis that the cognitive resources available to perform mental operations decline with aging has frequently been proposed since the 1980s (e.g., Craik and Byrd, 1982; Craik, Byrd, and Swanson, 1987). This processing resources hypothesis could account for many cognitive failures in various domains (Park and Hedden, 2001). In the inhibitory domain, this hypothesis has previously been proposed to explain the dissociation between intact performance on tasks assessing automatic inhibitory processes and impaired performance on tasks requiring controlled inhibition (Andrés et al., 2008; Collette, Germain, et al., 2009; Collette, Schmidt, et al., 2009). Indeed, controlled inhibition can be considered to demand more resources than automatic inhibition, in the sense that it is intentionally and deliberately engaged to resolve a conflict situation while automatic inhibition can be seen as a gating mechanism occurring prior to conscious awareness and preventing the processing of distracting information (Harnishfeger, 1995; Nigg, 2000). The results obtained here with our divided attention procedure support that interpretation since they showed that an increase in (or occurrence of) inhibitory problem is associated with the unavailability of cognitive resources.

Finally, the presence of significant correlations in the older group between backward span and performance in the divided attention condition of our two tasks (Go/No-Go: response times; conflict resolution: accuracy) is also in agreement with the hypothesis that the availability of cognitive working memory resources influences inhibitory efficiency; the older participants who were most able to divide their attention between storage and processing of information during the backward span task were the most efficient at the inhibitory tasks under the divided attention condition.

4.3. Effect of task-specific working memory load

The third part of this study was devoted to explore the effect of task-specific working memory load on inhibition. The results actually showed a decrease in inhibitory performance in both younger and older participants when task requirements were more complex and recruited more working memory resources (storage of instructions or number of items to process). This time, a supplementary effect of aging was observed only for the conflict resolution task (where the initial inhibitory performance of older adults was already impaired in the standard version). Although several previous studies had shown that span size influences young participants' inhibitory performance (Kane et al., 2001; Kane and Engel, 2003; Lustig et al., 2001), there exist few studies that directly investigated the effect of task-specific working memory load on inhibition. Mostofsky et al. (2003), in their fMRI study, used two different Go/No-Go tasks, one with a low working memory load (push a button for each green spaceship presented but not for red spaceships) and a counting version with a high working memory load (respond to green spaceships but also to red spaceships when preceded by an even number of green ones). No load effect was found when comparing reaction times and accuracy data on the two tasks. In another study, Redick et al. (2011) recently compared a standard Go/No-Go procedure (respond to one target but not to distracters) with a more working memory demanding conditional Go/No-Go (provide response for the two “Go” stimuli only when presented in alternation, and restrain responding for “No-Go” stimuli and “Go” stimuli when presented repeatedly), similar to the task used by Nielson et al. (2002, 2004), in high and low working memory span participants. Results evidenced no group difference in the standard version while low span individuals showed weaker performance compared to high span participants in the more complex conditional version. In line with their study, our experiment brought additional support that the working memory load characteristics of a task are likely to influence inhibitory functioning.

Our results are in agreement with the theoretical views of Hasher and Zacks (Hasher, Lustig, and Zacks, 2007) and Kane and Engle (2003), who clearly linked working memory capacity and inhibitory functioning. However, the results obtained here can be most easily interpreted in reference to Kane and Engle’s proposal that working memory capacities constrain attentional inhibition, or at least the consistency of its application (for a similar discussion, see also Conway and Engle, 1994; Kane et al., 2001; Rosen and Engle, 1998), rather than in reference to the proposal of Hasher et al. that inhibitory capabilities constrain working memory capacity.

Decreased span size in normal aging has often been reported in the literature (Grégoire and Van der Linden, 1997; Hester, Kinsella, and Ong, 2004). Similarly, we observed poorer performance on the forward digit span task, attesting to the reduction in working memory capacity in our sample of older adults. Significant correlations also exist between forward span size (reflecting storage capacity in working memory) and inhibitory performance (response times and accuracy of response) in the complex condition of the Go/No-Go task, as well as with inhibitory performance (response times) in the standard version of the conflict resolution task. So it can be considered that inhibitory efficiency in normal aging is determined by the task-related memory load, in the sense that tasks with a high memory load (for example, complex instructions or several stimulus-response associations to memorize) will tax (or even overload) older people's working memory capacity and thus significantly decrease their inhibitory efficiency. However, when the memory load associated with a task remains low and within the capacity range of older participants, this variable will not influence inhibitory performance. Thus, the decrease in performance was similar in young and elderly subjects from the standard to the complex version of the Go/No-task, in which two and three target stimuli, respectively, had to be maintained in working memory.

5. Conclusion

Our study confirmed the interaction between working memory and inhibitory functioning. The data obtained support a more quantitative approach to inhibitory functioning since the inhibitory effects observed within a single task (here, the Go/No-Go and conflict resolution tasks) are modulated by external factors, such as the cognitive resources available in working memory or the task-related working memory load. The inhibitory deficits associated with normal aging also seem to be influenced by these quantitative effects. Indeed, we observed a general (across tasks) effect of the amount of resources available in working memory on inhibitory abilities and an effect of the working memory load specific to the task administered, in the sense that older participants' inhibitory abilities will be lowered if the working memory task requirements tax or overload their working memory storage capacity. Consequently, age-related inhibitory decline can be conceived of, at least in part, as an indirect consequence of age-related changes in working memory functioning.

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References

Amieva, H., Phillips, L.H., Della Sala, S., & Henry, J.D. (2004). Inhibitory functioning in Alzheimer's disease. *Brain, 127*(5), 949-964.

Andrés, P., Guerrini, C., Phillips, L., & Perfect, T.J. (2008). Differential effects of aging on executive and automatic inhibition. *Developmental Neuropsychology, 33*(2), 1-23.

Aslan, A., Zellner, M., & Bäuml, K.H.T. (2010). Working memory capacity predicts listwise directed forgetting in adults and children. *Memory, 18*(4), 442-450.

Bélanger, S., & Belleville, S. (2009). Semantic inhibition impairment in Mild Cognitive Impairement: A distinctive feature of upcoming cognitive decline? *Neuropsychology, 23*(5), 592-606.

Bélanger, S., Belleville, S., & Gauthier, S. (2010). Inhibition impairments in Alzheimer's disease, mild cognitive impairment and normal aging : Effect of congruency proportion in a Stroop task. *Neuropsychologia, 48*, 581-590.

Belleville, S., Rouleau, N., & Van der Linden, M. (2006). Use of the Hayling task to measure inhibition of prepotent responses in normal aging and Alzheimer's disease. *Brain and Cognition, 62*, 113-119.

Bjorklund, D. F., & Harnishfeger, K. K. (1995). The evolution of inhibition mechanisms and their role in human cognition and behavior. In F. N. Dempster & C. J. Brainerd (Eds.), *Interference and inhibition in cognition* (pp. 141-173). San Diego, CA: Academic Press.

Bugg, J.M., DeLosh, E.L., Davalos, D.B., & Davis, H.P. (2007). Age differences in Stroop interference: Contributions of general slowing and task-specific deficits. *Aging, Neuropsychology, and Cognition, 14*(2), 155-167.

Castel, A.D., Balota, D.A., Hutchison, K.A., Logan, J.M., & Yap, M.J. (2007). Spatial attention and response control in healthy younger and older adults and individuals with

Alzheimer’s disease: Evidence for disproportionate selection impairments in the Simon task. *Neuropsychology, 21*(2), 170-182.

Castel, A.D., Pratt, J., & Craik, F.I.M. (2003). The role of spatial working memory in inhibition of return: Evidence from divided attention tasks. *Perception & Psychophysics, 65*(6), 970-981.

Charlot, V., & Feyereisen, P. (2004). Aging and the deletion function of inhibition. *Aging, Neuropsychology, and Cognition, 11*(1), 12-24.

Charlot, V., & Feyereisen, P. (2005). Episodic memory, inhibition deficit, and cognitive aging: An examination of the frontal hypothesis. *L'Annee Psychologique, 105*(2), 323-357.

Cohen, J.D., Dunbar, K., & McClelland, J.L. (1990). Automaticity, attention and the strength of processing: A parallel distributed processing account of the Stroop effect. *Psychological Review, 97*, 332-361.

Cohen, J.D., Servan-Schreiber, D., & McClelland, J.L. (1992). A parallel distributed processing approach to automaticity. *The American Journal of Psychology, 105*(2), 239-269.

Colflesh, G.J.H., & Conway, A.R.A. (2007). Individual differences in working memory capacity and divided attention in dichotic listening. *Psychonomic Bulletin & Review, 14*(4), 699-703.

Collette, F., Amieva, H., Adam, S., Hogge, M., Van der Linden, M., Fabrigoule, C., & Salmon, E. (2007). Comparison of inhibitory functioning in mild Alzheimer's disease and frontotemporal dementia. *Cortex, 43*(7), 866-874

Collette, F., Germain, S., Hogge, M., & Van der Linden, M. (2009). Inhibitory control of memory in normal ageing: dissociation between impaired intentional and preserved unintentional processes. *Memory, 17*(1), 104-122.

Collette, F., Schmidt, C., Scherrer, C., Adam, S., & Salmon, E. (2009). Specificity of inhibitory deficits in normal aging and Alzheimer's disease. *Neurobiology of Aging, 30*, 875-889.

Conway, A.R.A., Cowan, N., & Bunting, M.F. (2001). The cocktail party phenomenon revisited: The importance of working memory capacity. *Psychonomic Bulletin & Review, 8*(2), 331-335.

Conway, A.R.A., & Engle, R.W. (1994). Working memory and retrieval: A resource-dependent inhibition model. *Journal of Experimental Psychology: General, 123*(4), 354-373.

Conway, M.A., & Fthenaki, A. (2003). Disruption of inhibitory control of memory following lesions to the frontal and temporal lobes. *Cortex, 39*, 667-686.

Craik, F.I.M., & Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In F.I.M. Craik & S. Trehub (Eds.*), Aging and cognitive processes* (pp. 191-211). New York: Plenum.

Craik, F.I.M., Byrd, M., & Swanson, J.M. (1987). Patterns of memory loss in three elderly samples. *Psychology and Aging, 2*(1), 79-86.

Dagenbach, D., & Carr, T. H. (1994). *Inhibitory processes in attention, memory, and language*. San Diego, CA: Academic Press.

De Fockert, J.W., Rees, G., Frith, C.D., & Lavie, N. (2001). The role of working memory in visual selective attention. *Science, 291*, 1803-1806.

Deltour, J.J. (1993). Echelle de vocabulaire de Mill Hill de J.C. Raven. Adaptation française et normes européennes du Mill Hill et du Standard Progressive Matrices de Raven PM 38 [Mill Hill vocabulary scale of J.C. Raven. French adaptation and European norms]. Braine-le-Château, Belgium: L'Application des Techniques Modernes.

Dempster, F. N., & Brainerd, C. J. (1995). *Interference and inhibition in cognition*. San Diego, CA: Academic Press.

Dempster, F.N., & Corkill, A.J. (1999a). Individual differences in susceptibility to interference and general cognitive ability. *Acta Psychologica, 101*(2-3), 395-416.

Dempster, F.N., & Corkill, A.J. (1999b). Interference and inhibition in cognition and behavior: Unifying themes for educational psychology. *Educational Psychology Review, 11*(1), 1-88.

Dumas, J.A., & Hartman, M. (2008). Adult age differences in the access and deletion functions of inhibition. *Aging, Neuropsychology, and Cognition, 15*, 330-357.

Eenshuistra, R.M., Ridderinkhof, K.R., & van der Molen, M.W. (2004). Age-related changes in antisaccade task performance: Inhibitory control or working-memory engagement? *Brain and Cognition, 56*, 177-188.

Falkenstein, M., Hoormann, J., & Hohnsbein, J. (2002). Inhibition-related ERP components: Variation with modality, age, and time-on-task. *Journal of Psychophysiology, 16*(3), 167-175.

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.

Grégoire, J., & Van der Linden, M. (1997). Effect of age on forward and backward digit spans. *Aging, Neuropsychology, and Cognition, 4*(2), 140-149.

Harnishfeger, K. K. (1995). The development of cognitive inhibition: Theories, definitions, and research evidence. In F. N. Dempster & C. J. Brainerd (Eds.), *Interference and inhibition in cognition* (pp. 175-204). San Diego, CA: Academic Press.

Harnishfeger, K.K., & Bjorklund, D.F. (1993). The ontogeny of inhibition mechanisms: A renewed approach to cognitive development. In M.L. Howe & R. Pasnak (Eds.), *Emerging themes in cognitive development: Vol.1. Foundations* (pp. 28-49). New York: Springer-Verlag.

Hasher, L., Lustig, C., & Zacks, R. (2007). Inhibitory mechanisms and the control of attention. In A.R.A. Conway, C. Jarrold, M.J. Kane, A. Miyake & J.N. Towse (Eds.), *Variation in Working Memory* (PP. 227-249). New York: Oxford University Press.

Hasher, L., Zacks, R. T., & May, C. P. (1999). Inhibitory control, circadian arousal, and age. In D. Gopher & A. Koriat (Eds.), *Attention and performance XVII, Cognitive regulation of performance: Interaction of theory and application* (pp. 653-675). Cambridge, MA: The MIT Press.

Hester, R., & Garavan, H. (2005). Working memory and executive function: The influence of content and load on the control of attention. *Memory & Cognition, 33*(2), 221-233.

Hester, R.L., Kinsella, G.J., & Ong, B. (2004). Effect of age on forward and backward span tasks. *Journal of the International Neuropsychological Society, 10*, 475-481.

Hogge, M., Salmon, E., & Collette, F. (2008). Interference and negative priming in normal aging and in mild Alzheimer’s disease. *Psychologica Belgica, 48*(1), 1-23.

Houghton, G., & Tipper, S.P. (1994). A model of inhibitory mechanisms in selective attention. In D. Dagenbach & T.H. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 53-112). San Diego: Academic Press.

Juncos-Rabadán, O., Pereiro, A.X., & Facal, D. (2008). Cognitive interference and aging: Insights from a spatial stimulus-response consistency task. *Acta Psychologica, 127*, 237-246.

Kane, M.J., Bleckley, M.K., Conway, A.R.A., & Engle, R.W. (2001). A controlled-attention view of working –memory capacity. *Journal of Experimental Psychology: General, 130*(2), 169-183.

Kane, M.J., & Engle, R.W. (2003). Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop performance. *Journal of Experimental Psychology: General, 132*(1), 47-70.

Kane, M. J., Hasher, L., Stoltzfus, E. R., Zacks, R. T., & Connelly, S. L. (1994). Inhibitory attentional mechanisms and aging. *Psychology and Aging, 9*(1), 103-112.

Kramer, A. F., Humphrey, D. G., Larish, J. F., Logan, G. D., & Strayer, D. L. (1994). Aging and inhibition: Beyond a unitary view of inhibitory processing in attention. *Psychology and Aging, 9*(4), 491-512.

Kubo-Kawai, N., & Kawai, N. (2010). Elimination of the enhanced Simon effect for older adults in a three-choice situation: Ageing and the Simon effect in a go/no-go Simon task. *The Quarterly Journal of Experimental Psychology, 63*(3), 452-464.

Lavie, N., Hirst, A., de Fockert, J.W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology: General, 133*(3), 339-354.

Little, D.M., & Hartley, A.A. (2000). Further evidence that negative priming in the Stropp color-word task is equivalent in older and younger adults. *Psychology and aging, 15*(1), 9-17.

Logan, G. D., & Zbrodoff, N. J. (1979). When it helps to be misled: Facilitative effects of increasing the frequency of conflicting stimuli in a Stroop-like task. *Memory & Cognition, 7*(3), 166-174.

Logan, G.D., & Zbrodoff, N.J. (1998). Stroop-type interference: Congruency effects in color naming with typewritten responses. *Journal of Experimental Psychology: Human Perception and Performance, 24*(3), 978-992.

Lustig, C., Hasher, L., & Tonev, S.T. (2006). Distraction as a determinant of processing speed. *Psychonomic Bulletin & Review, 13*(4), 619-625.

Lustig, C., May, C.P., & Hasher, L. (2001). Working memory span and the role of proactive interference. *Journal of Experimental Psychology: General, 130*(2), 199-207.

Manly, T., Robertson, I.H., Galloway, M., & Hawkins, K. (1999). The absent mind: Further investigations of sustained attention to response. *Neuropsychologia, 37*, 661-670.

Mattis, S. (1976). Dementia rating scale. In R. Bellack &B.Keraso (Eds.), *Geriatric psychiatry X* (pp. 77–121). New York: Grune and Stratton.

May, C.P., & Hasher, L. (1998). Synchrony effects in inhibitory control over thought and action. *Journal of Experimental Psychology: Human Perception and Performance, 24*(2), 363-379.

Mitchell, J.P., Macrae, C.N., & Gilchrist, I.D. (2002). Working memory and the suppression of reflexive saccades. *Journal of Cognitive Neuroscience, 14*(1), 95-103.

Monsch, A.U., Bondi, M.W., Salmon, D.P., Butters, N., Thal, L.J., Hansen, L.A., Wiederholt, W.C., Cahn, D.A., & Klauber, M.R. (1995). Clinical validity of the Mattis dementia rating scale in detecting dementia of the Alzheimer type. *Archives of Neurology, 52*(9), 899–904.

Mostofsky, S.H., Schafer, J.G.B., Abrams, M.T., Goldberg, M.C., Flower, A.A., Boyce, A., Courtney, S.M., Calhoun, V.D., Kraut, M.A., Denckla, M.B., & Pekar, J.J. (2003). fMRI evidence that the neural basis of response inhibition is task-dependent. *Cognitive Brain Research, 17*, 419-430.

Nassauer, K. W., & Halperin, J. M. (2003). Dissociation of perceptual and motor inhibition processes through the use of novel computerized conflict tasks. *Journal of the International Neuropsychological Society, 9*(1), 25-30.

Nelles, G., de Greiff, A., Pscherer, A., & Esser, J. (2009). Afe-related differences of saccade induced cortical activation. *Neuroscience Letters, 458*, 15-18.

Nielson, K. A., Langenecker, S. A., & Garavan, H. (2002). Differences in the functional neuroanatomy of inhibitory control across the adult life span. *Psychology and Aging, 17*(1), 56-71.

Nielson, K.A., Langenecker, S.A., Ross, T.J., Garavan, H., Rao, S.M., & Stein, E.A. (2004). Comparability of functional MRI response in young and old during inhibition. *Neuroreport*, *15*(1), 129-133.

Nieuwenhuis, S., Yeung, N., van den Wildenberg, W., & Ridderinkhof, K.R. (2003). Electrophysiological correlates of anterior cingulate function in a go/no-go task: Effects of response conflict and trial type frequency. *Cognitive, Affective, & Behavioral Neuroscience*, *3*(1), 17-26.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological bulletin, 126*(2), 220-246.

Park, D.C., & Hedden, T. (2001). Working memory and aging. In M. Naveh-Benjamin, M. Moscovitch & H. L. I. Roediger (Eds.), *Perspectives on Human Memory and Cognitive Aging. Essays in Honour of Fergus Craik.* (pp. 148-160). New York: Psychology Press.

Peltsch, A., Hemraj, A., Garcia, A., & Munoz, D.P. (in press). Age-related trends in saccade characteristics among the elderly. *Neurobiology of Aging*.

Redick, T.S., Calvo, A., Gay, C.E., & Engle, R.W. (2011). Working memory capacity and Go/No-Go task performance: Selective effects of updating, maintenance, and inhibition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*(2), 308-324.

Rhodes, M.G. (2004). Age-related differences in performance on the Winsconsin Card Sorting Test: A meta-analytic review. *Psychology and Aging*, *19*(3), 482-494.

Roberts, R.J., Hager, L.D., & Heron, C. (1994). Prefrontal cognitive processes: Working memory and inhibition in the antisaccade task. *Journal of Experimental Psychology: General, 123*(4), 374-393.

Roberts, R.J., & Pennington, B.F. (1996). An interactive framework for examining prefrontal cognitive processes. *Developmental Neuropsychology, 12*(1), 105-126.

Rosen, V.M., & Engle, R.W. (1998). Working memory capacity and suppression. *Journal of Memory and Language, 39,* 418-436.

Rush, B. K., Barch, D. M., & Braver, T. S. (2006). Accounting for cognitive aging: context processing, inhibition or processing speed? *Aging, Neuropsychology and Cognition, 13*(3-4), 588-610.

Salthouse, T.A., & Babcock, R.L. (1991). Decomposing adult age differences in working memory. *Developmental Psychology, 27*(5), 763-776.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime user's guide*. Pittsburgh, PA: Psychology Software Tools Inc.

Shuster, J., & Toplak, M. E. (2009). Executive and motivational inhibition: Associations with self-report measures related to inhibition. *Consciousness and Cognition, 18*(2), 471-480.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*(6), 643-662.

Stuyven, E., Van der Goten, K., Vandierendonck, A., Claeys, K., & Crevits, L. (2000). The effect of cognitive load on saccadic eye movements. *Acta Psychologica, 104,* 69-85.

Unsworth, N., Schrock, J.C., & Engle, R.W. (2004). Working memory capacity and the antisaccade task: Individual differences in voluntary saccade control. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30*(6), 1302-1321.

Verhaegen, P., & De Meersman, L. (1998). Aging and the negative priming Effect: A meta-analysis. *Psychology and aging, 13*(3), 435-444.

Verhaegen, P., Steitz, D.W., Sliwinski, M.J., & Cerella, J. (2003). Aging and dual-task performance: A meta-analysis. *Psychology and Aging, 18*(3), 443-460.

Welsh, M.C., Satterlee-Cartmell, T., & Stine, M. (1999). Towers of Hanoi and London: Contribution of working memory and inhibition to performance. *Brain and Cognition*, *41*, 231-242.

Witthöft, M., Sander, N., Süb, H. M., & Wittmann, W. W. (2009). Adult age differences in inhibitory processes and their predictive validity for fluid intelligence. *Aging, Neuropsychology and Cognition*, *16*(2), 133-163.

Zimmerman, P., & Fimm, B. (1994). *Tests d'évaluation de l'attention* (TEA). Würselen, Deutschland: Psytest.

Figure 1. Mean reaction times (msec) in the Go/No-Go task (a) and in the conflict resolution task (b) as a function of test phase and prepotency condition in young and elderly participants. Error bars represent standard deviations.

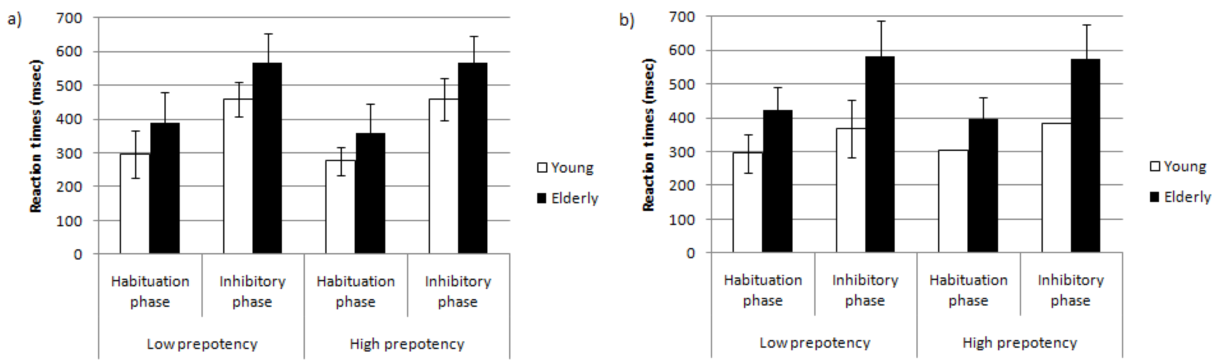

Figure 2. Mean reaction times (msec) in the Go/No-Go task (a) and in the conflict resolution task (b) as a function of general working memory involvement condition in young and elderly participants. Error bars represent standard deviations.

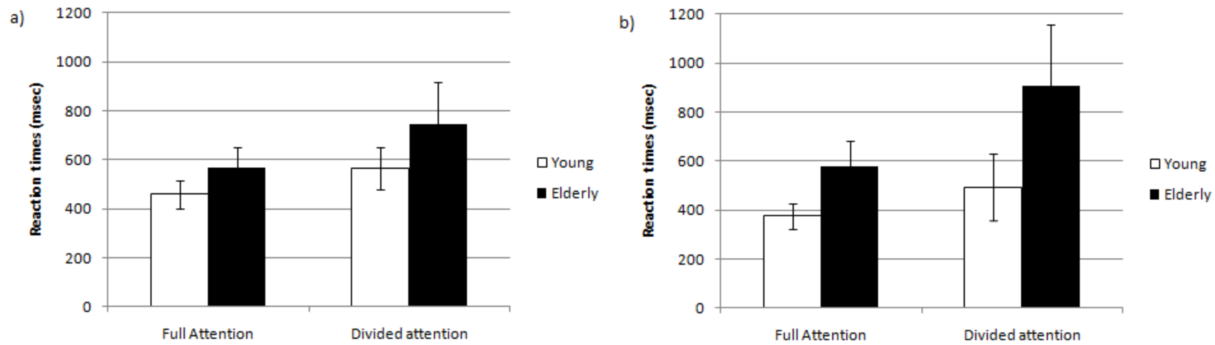

Figure 3. Mean reaction times (msec) in the Go/No-Go task (a) and in the conflict resolution task (b) as a function of task-specific working memory load condition in young and elderly participants. Error bars represent standard deviations.