Perceptual and motor inhibitory abilities in normal aging and Alzheimer disease: A preliminary study

Short title: Inhibition in normal aging and Alzheimer's disease

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Abstract

Deficits in inhibitory abilities are frequently observed in normal aging and Alzheimer disease (AD). However, few studies have explored the generality of these deficits in a single group of participants. A battery of tasks assessing perceptual and motor inhibitory functioning was administered to young and older healthy participants (Study 1), as well as to mild Alzheimer patients (Study 2). Results did not agree with a selective impairment of motor or perceptual inhibition in either AD or normal aging but rather suggest that a decrease in cognitive resources available in working memory could explain inhibitory performance both in normal aging and AD.

Key words: motor inhibition; perceptual inhibition; normal aging; Alzheimer disease

1. Introduction

Inhibition is a basic aspect of cognitive and emotional functioning involved in the performance of numerous tasks and processes and whose correct functioning is necessary to maintain an adequate level of adjustment to environmental demands (e.g., Nigg, 2000). Inhibition is generally defined as the set of processes that allow the suppression of previously activated cognitive contents, the clearing of irrelevant actions or of attentional focus from consciousness, and the resistance to interference from potentially attention-capturing stimuli (Bjorklund & Harnishfeger, 1995). Deficits in inhibitory abilities are proposed as one of the causes of the diminished daily functioning characterizing normal aging and Alzheimer disease (AD; e.g., Amieva, Phillips, Della Sala, & Henry, 2004; Collette & Van der Linden, 2002; Harnishfeger, 1995; Harnishfeger & Bjorklund, 1993).

Recently, several theoretical frameworks have been proposed to explain the inhibitory effects reported in the literature in various normal and pathological populations. For instance, inhibition was specifically related to working memory by Hasher, Zacks, and May (Hasher, Tonev, Lustig, & Zacks, 2001; Hasher, Zacks, & May, 1999), who described three general inhibitory functions that operate at different times in the information processing sequence: the access function, preventing access to irrelevant information; the deletion function, suppressing information that either is or becomes irrelevant; and the restraint function, which operates when strong responses are triggered by a familiar cue but do not have to be produced. Other authors viewed inhibition as a general process operating in various cognitive domains. In that context, Dempster and Corkill (1999a, 1999b) have suggested making a distinction between perceptual, motor and verbal inhibition. Inhibitory tasks were also classified according to the following three dimensions: (1) intentional vs. unintentional, (2) behavioral vs. cognitive, and (3) inhibition vs. interference (Harnishfeger, 1995). More generally, Nigg (2000) suggested dissociating effortful inhibitory processes (for example, cognitive inhibition, behavioral inhibition and oculo-motor inhibition) from automatic inhibition of attention (concerning inhibition of irrelevant spatial *locations* or of recently inspected stimuli). Finally, Kipp Harnishfeger (Harnishfeger, 1995; Harnishfeger & Bjorklund, 1993; Wilson & Harnishfeger, 1998), proposed *a distinction* between the concepts of inhibition and interference. In that theoretical framework, inhibitory control

corresponds to a voluntary suppression of the information, and interference resolution represents a gating mechanism preventing the processing of distracting information. More precisely, Kipp Harnishfeger proposed that interference resolution consists of an automatic/unintentional process occurring prior to conscious awareness while inhibition results when a stimulus is classified as irrelevant for the ongoing task and is then consciously/intentionally suppressed. By reference to daily life activities, intentional inhibition would correspond to avoiding black chocolate ice cream that you do not like, while unintentional inhibition might correspond to "automatically" taking vanilla ice cream, while you might have enjoyed white chocolate ice cream. Perceptual inhibition would correspond to avoiding any brown ice cream because you do not like black chocolate, while motor suppression would result from your neighbor telling you not to take his ice cream.

A large number of studies exploring inhibition in normal aging and Alzheimer's disease demonstrated impaired abilities using various tasks and procedures. For example, difficulties in inhibiting prepotent responses were observed in these populations on Stroop[1] (e.g., Balota & Faust, 2001; Spieler, Balota, & Faust, 1996), negative priming[2] (Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994; McDowd & Oseas-Kreger, 1991) and Hayling tasks[3] (Andres & Van der Linden, 2000; Collette, Van der Linden, & Salmon, 1999), as well as on the stop-signal[4] (Kramer, Humphrey, Larish, Logan, & Strayer, 1994; May & Hasher, 1998), go/no-go[5] (Nielson, Langenecker, & Garavan, 2002) and anti-

[1] The interference Stroop effect refers to the increased latency time to name the color of the ink with which an item is printed when the item is the name of another color (e.g. the word "red" printed in green) in comparison to neutral stimuli (e.g. the item "XXX" also printed in green).

[2] In the negative priming procedure, subjects are simultaneously shown two items (e.g., letters), one red (target) and the other green (distractor). Subjects are instructed to process the red item as quickly as possible and to ignore the green one. The negative priming effect corresponds to response time increase when the item serving as the distractor in one trial (prime) is used as the target in the very next trial (probe). The explanation for this effect is that the distractor is actively inhibited in the prime trial.

[3] In the Hayling task, subjects are asked to complete sentences in which the final word is omitted, either with an appropriate word ("initiation" condition) or with a word that makes no sense at all in the context of the sentence ("suppression" condition). In comparison to the first condition, the second condition requires inhibiting the automatically activated word in order to provide a word unrelated to the context of the sentence.

[4] In the stop/signal task, participants have to categorize items (i.e. living/no-living) as quickly as possible but to suppress the production of the response following the appearance of a warning signal in a short delay after the presentation of some items.

[5] The go/no-go task requires pressing a response key as quickly as possible when target items are presented but to withhold that motor response following the presentation of distracters items.

saccade[6] (Butler, Zacks, & Henderson, 1999) tasks. However, a negative effect of normal aging and AD on suppression abilities has not been systematically observed. In older participants, some studies demonstrated no evidence of impairment for the Stroop task (Kieley & Hartley, 1997), as well as for negative priming (Buchner & Mayr, 2004; Gamboz, Russo, & Fox, 2002) and inhibition of return[7] tasks (Hartley & Kieley, 1995). In a similar way, normal inhibition-of-return effects are observed in AD patients (Faust & Balota, 1997; Langley, Fuentes, Hochhalter, Brandt, & Overmier, 2001) and little evidence of dysfunction has been found in tasks assessing motor response inhibition (Amieva et al., 2002; Collette et al., 2007).

Additionally, studies in which batteries of tasks were used also showed that some aspects of inhibition can be preserved in normal aging and AD. For instance, dissociation between impaired intentional inhibitory abilities and preserved unintentional ones was reported in two studies. Collette, Germain, Hogge, and Van der Linden (2009) compared the performances of normal elderly and young participants on tasks involving either intentional or unintentional inhibitory control of memory content. Their results suggested that normal aging is associated with a specific dysfunction affecting intentional inhibitory control of memory contents. In addition, Andrès et al. showed that older subjects' performances were impaired in the Stroop test and in the stop-signal task (that can be considered as effortful or intentional) while automatic inhibition, as assessed by a negative priming task, was spared (Andres, Guerrini, Phillips, & Perfect, 2008). With regard to Alzheimer's disease, Amieva et al. (2002) observed impaired performance on the negative priming and Stroop tasks, but not on the go/no-go task, and only limited impairment was observed on the stop-signal task, suggesting that motor response inhibition could be relatively spared in that group of patients (for similar data on the Stroop and go/no-go task, see also Collette, et al., 2007).

As a whole, results of these studies indicate that not all aspects of inhibitory functioning are impaired in normal and pathological aging, and that not exactly the same processes could be altered in these two populations. However, very few of these studies tried to relate the performance of elderly

[6] The anti-saccade task necessitates inhibiting automatic ocular saccades from the location where a non-relevant item is presented.

[7] The phenomenon of Inhibition of return consists *of* a slowing down in the processing of items appearing at a spatial location where attention was focalized shortly before the presentation of these items.

participants and AD patients to *a* theoretical framework of inhibition. In that context and according to the proposal of Dempster and Corkill that there exists an earlier development of motor than perceptual inhibition during childhood (Dempster & Corkill, 1999a, 1999b), the existence of a specific impairment of perceptual versus motor inhibitory functioning appears particularly interesting to investigate in these populations. Two studies (Germain & Collette, 2008; Jennings, Mendelson, Redfern, & Nebes, 2011) explored this question in normal aging using a task assessing separately resistance to perceptual and motor interference within the context of very similar stimulus and response demands (Nassauer & Halperin, 2003). The two studies showed both decreased perceptual and motor inhibitory abilities in older participants. With regard to AD, some preliminary evidences tend to demonstrate that motor inhibition could be relatively spared in the early stages of the illness (Amieva, et al., 2002; Collette, et al., 2007).

However, at this time, no study explored perceptual and motor inhibitory functioning simultaneously in a large range of tasks in healthy older participants and AD patients to determine if aging (and more particularly AD) is associated to a (relative) preservation of motor inhibition that would correspond to the reverse of the developmental course proposed by Dempster & Corkill (Dempster & Corkill, 1999a, 1999b). Consequently, in the present study, seven inhibitory tasks were administered to four groups of participants: a group of young and a group of older participants (Study 1) as well as a group of mild AD patients and a group of matched healthy participants (Study 2). The tasks included in our battery were selected according to two main criteria. They are generally considered in the literature as involving mainly perceptual or motor inhibitory processes (Amieva, et al., 2004) and they were administered to aging populations in previous studies (with the exception of the Simon task for AD patients). Other task characteristics such as the un(intentional) aspect of inhibition, the working memory load or the verbal/visual component were not taken into account since it was not possible to equate these aspects between motor vs. perceptual inhibition tasks. The three tasks assessing perceptual inhibition were a variant of the Stroop test (Stroop, 1935) used to assess both the classical Stroop interference and the negative priming effects (Tipper, 1985), the perceptual condition of the Simon task previously proposed by Nassauer & Halperin (2003) and the Eriksen's flanker task (Eriksen & Eriksen, 1974). The four motor inhibitory tasks were an anti-saccade task

(Roberts, Hager, & Heron, 1994), a go/no-go task (Zimmerman & Fimm, 1994), the motor condition of the Simon task (Nassauer & Halperin, 2003) and a stop-signal task (Logan, 1994; Logan, Cowan, & Davis, 1984) . *The novel aspect of this study is the administration of several tasks* assessing motor and perceptual inhibition to the same group of participants. Such a procedure allows ascertaining that the presence of specific perceptual or motor inhibitory deficits cannot be explained by confounding factors related to the characteristics of the participants (as this is the case when results from different studies/populations are compared).

Study 1. The effect of normal aging on perceptual and motor inhibition

Methods

Participants

Forty adults volunteered to participate in this study. The 20 younger adults (10 men and 10 women) had an average age of 22.1 years (SD = 2.6; range: 18-30). The 20 normal elderly subjects (10 men and 10 women) had an average age of 64.9 years (SD = 4.6; range: 60-75). All healthy older adults were involved in leisure and/or voluntary work activities and lived independently in their own house. Subjects with medical disorders, neurological disorders, psychiatric disorders or medication/substance histories that could affect cognitive functions were excluded from the study. A French adaptation of the Mill-Hill Vocabulary Scale (multiple-choice form; Deltour, 1993) was administered to all participants to assess crystallised verbal ability. No difference was found between the two groups on this scale [$t(38) = .98$, $p = .33$, $d = .31$; younger adults: 24.75 ± 4.01; elderly participants: 23.15 ± 6.09]. The elderly participants were also given the Mattis Dementia Rating Scale (Mattis, 1973), which is widely used to screen for dementia. All elderly participants had a total score superior to 123 on this scale ($M = 140.3$, $SD = 2.52$, range: 133-143).

Procedure

The participants were tested individually in a one-hour and a half session in a quiet well-lightened room. All inhibition computerized tasks were presented on a PC-compatible computer interfaced with a 14-inch SVGA color monitor using E-Prime software version 1.0 (Schneider, Eschman, & Zuccolotto, 2002). Participants were seated in front of the computer screen so that their

eyes were approximately 70 cm from the display. Except for the Stroop task which required vocal responses, all response keys were located on a standard keyboard. For each participant, the tasks were administered in the following order: Stroop task, stop-signal task, perceptual Simon task, motor Simon task, go/no-go task, flanker tasks, saccadic task, Mattis Dementia Rating Scale (for elderly participants only), Mill-Hill Vocabulary Scale. Before the beginning of each task, participants were given practice trials and additional explanations as necessary *to ensure* the full understanding of tasks instructions.

Cognitive tasks

Perceptual inhibition

Stroop task

This task was adapted from the task used by Hogge et al. in a previous study (Hogge, Salmon, & Collette, 2008). Four different colors (red, blue, yellow and green) were used to create three sets of stimuli: colored strings of %%%, congruent stimuli and incongruent stimuli. The incongruent stimuli were created by printing each of the four color names in the three other ink colors (e.g., RED printed in green ink). The congruent stimuli were created by printing each of the four color names in its own color (e.g., RED printed in red ink). These sets of stimuli were combined in order to create five different types of stimuli: 18 congruent stimuli, or F (facilitator); 36 incongruent stimuli, or I; 18 positively primed incongruent stimuli, or I+ (the color of the stimuli on trials n–1 and n were the same, but the color names were different); 18 negatively primed incongruent stimuli, or I– (the irrelevant word on trial n–1 was the same as the relevant color on trial n); and 18 neutral stimuli, or N (%%%). An incongruent stimulus was always followed by a neutral one (72 in total), which served as a filler to prevent an unwanted priming effect on the next trial, except, of course, the ones that served as primes. The whole task was therefore composed of 144 stimuli.

Subjects were asked to say aloud, as quickly and accurately as possible, the ink color in which each stimulus was printed, while ignoring the word itself. Stimuli were presented individually in the center of a black background and were preceded for 500 ms by a sound, instead of a fixation cross. Each stimulus remained on the screen until the subject gave his or her response. In order to minimize loss of trials and inaccurate reaction time measurement due to hesitation, a correction method was developed that allows us to avoid the problems inherent in the use of vocal keys (i.e., extensive loss of

trials and inaccurate reaction time measurement). More specifically, subject responses were recorded by a voice recorder and were corrected latter with Sound Forge 7.0. (Sony®), which allowed us to generate the waves of the warning sound and the subject's response for each trial in order to determine response time with millisecond accuracy. We preferred this technique to the classical vocal key because the latter is less precise since the first sound pronounced by the subject is systematically recorded as the response. Thus, with a vocal key, every trial for which the subject hesitated (by saying, for example, "ehhhhh," "gre … red") before responding correctly is likely to be lost, while this was not the case with our technique, which allowed us to accurately identify the start of the wave associated with the correct response (in the example: "… red"). Because negative priming depended *on* the correct inhibition of the previous I stimuli, I- simuli following an error were excluded from the reaction time analysis. The Stroop task allowed us to explore simultaneously two perceptual inhibitory effects, interference and negative priming. The interference effect was assessed by comparing performance of the subjects on neutral and interferent stimuli while the negative priming effect was assessed by comparing the median reaction time associated with the I- stimuli to the median reaction time associated with the I stimuli.

Perceptual Simon task

The Perceptual Simon task, as well as the Motor Simon task (see below), were adapted from Nassauer and Halperin (2003). This task comprised two conditions. The first condition involved 40 trials in which a rectangular box appeared randomly either on the right (20 trials) or left (20 trials) side of the computer screen. The presentation of each stimulus was preceded by a fixation cross (1 sec.). Subjects were asked to press the key located on the same side as the rectangle as quickly and accurately as possible before the disappearance of the stimulus (3 sec.). The purpose of this habituation condition was to elicit the tendency to respond according to the location of the stimuli. The second condition was an inhibitory one and consisted *of* 120 randomized trials in which a left or right pointing arrow appeared on the left, on the right or in the middle of the computer screen. This condition was thus composed of three 3 kinds of stimuli : "facilitator stimuli" (40 trials) when the direction of the arrow and its location were congruent (i.e. a right pointing arrow located on the right side of the computer screen), "interferent stimuli" (40 trials) when the direction of the arrow and its

location were incongruent (i.e. a right pointing arrow located on the left side of the computer screen) and "neutral stimuli" (40 trials) when arrows appeared in the middle of the computer screen. The instructions given to the subjects were to respond according to the direction of the arrow no matter where its location was. Thus, for the interferent stimuli subjects were required to inhibit their tendency (strengthened by the habituation condition) to respond to the location of the stimulus. As in the habituation condition, a fixation cross appeared for one sec. before each trial and stimuli disappeared after 3 sec. if no response was performed. The interference effect was assessed by comparing performance of the subjects on neutral and interferent stimuli in the inhibition condition.

Flanker Task

This task was an adaptation of that used by Eriksen and Eriksen (1974). During each trial, groups of five terms were presented on a single line in the middle of the screen. Each group was composed of a central target (B, H, T or F) surrounded by four flankers (two on each side). In each trial the four flankers were similar and were either string of two asterisks (e.g. **H**) or of two letters (B, H, T or F [e.g. HHTHH], with the exception that the flankers' letter and the target letter could not be the same). Subjects were asked to ignore the flankers and to concentrate only on the central target letter. They were asked to press the response key located on the left when the central target letter was either B or H and to press the response key located on the right if the target letter was either T or F, as quickly and accurately as possible before the disappearance of the stimulus (3 sec.). The presentation of each stimulus was preceded by a fixation cross (1.3 sec.). This task was composed of 72 trials and of three kinds of items: "facilitator" (24 trials), when the central target letter and the flankers were letters associated to the same response key (i.e. FFTFF), "neutral" (24 trials), when the target letter was surrounded by four asterisks (i.e. **H**), and "interferent" (24 trials), when the targets letter and the flankers were associated to different response keys (i.e. HHTHH). The interference effect was assessed by comparing performance of the subjects on neutral and interferent items.

Motor inhibition

Saccadic task

This task, adapted from that used by Roberts et al. (1994) was composed of two conditions. For each trial in both conditions, a fixation cross was first presented in the middle of the computer screen for a variable amount of time ranging from 500 to 2500 ms. A visual cue was then presented at the farthest left or right point of the screen for 225 ms, followed by the presentation of the target stimulus for 150 ms before it was masked by gray cross-hatching. In the control pro-saccade condition, the target stimulus was presented on the same side as the visual cue whereas in the inhibition anti-saccade condition, it was presented on the opposite side. The visual cue was a white square, and the target stimulus consisted of an arrow. The participant's task was to indicate the direction of the arrow (left, up, or right) with three response keys. In both condition, participants were instructed to look at the fixation cross before the occurrence of the initial cue. Given that the arrow appeared for only 150 ms. before being masked, participants were additionally instructed to inhibit their reflexive eye response to the initial cue in the anti-saccade condition, because this response would make it difficult to correctly identify the position of the arrow. No specific instruction regarding the initial cue was given in the pro-saccade condition. 108 stimuli were randomly presented in each condition and the two conditions were matched on the parameters of fixation cross duration, arrow orientation and side of appearance, and sorted randomly in order to compose the task. The interference effect was assessed by comparing performance of the subjects on items from the control pro-saccade condition with those from the anti-saccade inhibition condition.

Go/no-go task

This task was adapted from Zimmerman and Fimm (Zimmerman & Fimm, 1994) and was again composed of two conditions. First, subjects were asked to perform a simple reaction time task. They had to respond as quickly as possible, by pressing a key response, to the visual presentation of the stimuli (two 3D abstract colored figures). Stimuli disappeared after 2 sec or the production of the response. 40 trials, were presented, separated by a variable amount of time ranging from 400 ms to 1600 ms. The go/no-go condition was next performed. It comprised 60 trials in which subjects were presented with either one of the two target stimuli used in the first part or one of three new stimuli, in a pseudo-random order. Subjects were told to respond again as quickly as possible to the target stimuli but not to the new ones. Two-thirds of the trials were 'Go' trials and the last third was 'No-go' trials.

The interference effect was assessed by comparing performance of the subjects on items from the simple reaction time condition with 'Go' trials from the go/no-go condition as well as by examining accuracy of response for the 'No-go' trials.

Motor Simon task

This task adapted from Nassauer and Halperin (2003) was composed of two conditions. As in the perceptual Simon task, the first condition involved 40 trials in which a rectangular box appeared randomly either on the right (20 trials) or left (20 trials) side of the computer screen. The presentation of each stimulus was preceded by a fixation cross (1 sec.) Subjects were asked to press the key located on the same side as the rectangle as quickly and accurately as possible before the disappearance of the stimulus (3 sec.). The purpose of this habituation condition was to elicit the tendency to respond following the location of the stimuli. The second condition was similar to the first one except for the instruction given to the participants: they are now asked to press the response key situated on the opposite side as the rectangle. This required inhibition of the motor response whose habituation was elicited during the first condition. As in the perceptual Simon task, the interference effect was assessed by comparing performance of the subjects on items from the habituation condition with the stimuli from the inhibition condition.

Stop-signal task

This task was adapted from that used by Logan et al. (Logan, 1994; Logan, et al., 1984). The task was composed of 24 words belonging to the living category (animals, insects, birds and fishes) and 24 words belonging to the non-living category (metals, pieces of furniture, musical instruments and tools). Each category was represented by three words matched on lexical frequency, word length and level of prototypy. Words were presented one at a time in the center of the screen. In the first (habituation) condition subjects were asked to press one of two response keys as quickly and accurately as possible depending on the word's category. This habituation condition was composed of 48 trials. Words were presented for 2 sec. and each stimulus was preceded by a fixation cross (500 msec.). The second (inhibition) condition was strictly similar to the first one in term of words presentation except that it was composed of 192 trials and that a sound was presented soon after the appearance of 48 randomly selected of those trials. Subjects were still asked to press one of two key-

responses as quickly and accurately as possible depending of the word's category (in the same way as in the first condition) but they were also informed of the presence of the sound following the appearance of some stimuli and were given the additional instruction of trying to stop their ongoing response as soon as they heard it. This condition thus required the inhibition of an already elicited motor response. For each subject, the interval between the appearance of the word and the warning signal corresponds to its mean response time for correct responses in the first condition minus 225 msec. For example, if a subject had a mean response time for correct responses in the first condition of 825 msec. then the onset of the sound for the second condition was 600 msec. after the appearance of the target words. The interference effect was assessed by comparing reaction times on trials in the habituation condition to non-stop trials in the inhibition condition, as well as by comparing stop accuracy in the inhibition condition.

Results

Statistical analyses mainly consisted of two-way mixed ANOVAs with conditions/items as a repeated measures factor. Following the recommendations of the additive factor method (Sergeant, 1996; Sergeant & van der Meere, 1990) non-inhibitory items/conditions were included in the analyses in order to control for the cognitive processes that were not of specific interest to the current study (e.g., processing speed). In the absence of neutral condition/items (e.g., stop accuracy in the stop-signal task), independent *t-tests* were used to compare performance between the two groups. A statistical level of $p < .05$ was used for each analysis. The effect size was reported as partial eta squared (η_p^2) for the ANOVAs' main effects and interaction effects. Cohen's d (*d*) was used as indicative of effect size for the *t-tests*. Partial eta squared is generally interpreted as the proportion of variance of the dependent variable that is related to the factor. Traditionally, eta squared values of .01, .06, and .14 and *d* values of .2, .5, and .8 represent small, medium and large effect sizes, respectively. Median response times (RTs) were used to reduce the influence of trials with extreme value, and were further log transformed to reduce between-group variability (e.g., Witthoft, Sander, Suss, & Wittmann, 2009). Inhibitory abilities were measured both by RTs and by response accuracy. Analyses reported

here concern solely the conditions/stimuli relevant to the comparison of inhibitory abilities between the two groups of participants.

Perceptual inhibition

Stroop task. Means of median RTs for correct responses and response accuracy for the three critical types of items (I: interferent items, I-: negatively primed interferent items, N: neutral items) are presented in Table 1. The critical features of behavioral performance concern the comparison of the I to N trials (interference effect) and the comparison of I- trials to I trials (negative priming effect). To ensure that I- trials were effectively negatively primed, only I- trials preceded by correctly performed I trials were taken into consideration.

Analyses on RTs for the interference effect demonstrated a main effect of group [$F(1,38) = 19.63$, $p < .01$; $\eta_p^2 = .34$], a main effect of stimuli type [$F(1,38) = 351.49$, $p < .01$, $\eta_p^2 = .90$] and the interaction effect was also significant [$F(1,38) = 12.18$, $p < .01$, $\eta_p^2 = .24$], indicating a larger interference effect in elderly participants than in younger. Analyses on response accuracy for the interference effect demonstrated a main effect of stimuli type [$F(1,38) = 13.90$, $p < .01$, $\eta_p^2 = .27$] but the main effect of group [$F(1,38) = 1.56$, $p = .22$; $\eta_p^2 = .04$], and the interaction effect [$F(1,38) = .10$, $p = .75$, $\eta_p^2 < .01$] were not significant. These analyses indicate that normal aging is characterized by a deficit in inhibitory abilities for the interference effect of the Stroop task, taking form of a slowing down of RTs.

Analyses on RTs for the negative priming effect demonstrated a main effect of group [$F(1,38) = 30.27$, $p < .01$; $\eta_p^2 = .44$], a main effect of stimuli type [$F(1,38) = 26.97$, $p < .01$, $\eta_p^2 = .42$] but the interaction effect was not significant [$F(1,38) = .06$, $p = .81$, $\eta_p^2 < .01$]. Analyses on response accuracy for the negative priming effect did not demonstrate a significant main effect of group [$F(1,38) = .23$, $p = .63$, $\eta_p^2 < .01$], stimuli type [$F(1,38) = .04$, $p = .84$; $\eta_p^2 < .01$], or interaction effect [$F(1,38) = .05$, $p = .82$, $\eta_p^2 < .01$]. These analyses indicate a preserved negative priming effect in normal aging.

[Insert Table 1 near here]

Perceptual Simon task. Means of median RTs for correct responses and response accuracy for the neutral and interferent stimuli are presented in Table 1. RTs analyses demonstrated a main effect of group [$F(1,38) = 46.87$, $p < .01$, $\eta_p^2 = .55$], a main effect of stimuli type [$F(1,38) = 108.10$, $p < .01$, $\eta_p^2 = .74$] and the interaction effect was also significant [$F(1,38) = 6.79$, $p < .05$, $\eta_p^2 = .15$], indicating the presence of a larger interference effect in older than young participants. Analyses on response accuracy demonstrated a main effect of stimuli type [$F(1,38) = 15.86$, $p < .01$; $\eta_p^2 = .29$] but the main effect of group [$F(1,38) = .79$, $p = .38$, $\eta_p^2 = .02$], and the interaction effect [$F(1,38) = .09$, $p = .76$, $\eta_p^2 < .01$] were not significant. These analyses indicate a deficit in inhibitory abilities for the perceptual Simon task in normal aging, taking form of a slowing down of RTs.

Flanker task. Means of median RTs for correct responses and response accuracy for the neutral and interferent stimuli are presented in Table 1. RTs analyses demonstrated a main effect of group [$F(1,38) = 29.80$, $p < .01$, $\eta_p^2 = .44$], a main effect of stimuli type [$F(1,38) = 4.32$, $p < .05$, $\eta_p^2 = .10$], but the interaction effect was not significant [$F(1,38) = .32$, $p = .57$, $\eta_p^2 = .01$]. Response accuracy analyses demonstrated a main effect of stimuli type [$F(1,38) = 10.98$, $p < .01$; $\eta_p^2 = .22$] but the main effect of group [$F(1,38) = 3.35$, $p = .08$, $\eta_p^2 = .08$] and the interaction effect [$F(1,38) = .02$, $p = .89$, $\eta_p^2 < .01$] were not significant. These analyses indicate preserved inhibition in normal aging for the flanker task.

Motor inhibition

Saccadic task. Means of median RTs for correct responses and response accuracy for the pro-saccade and anti-saccade conditions are presented in Table 2. RTs analyses demonstrated a main effect of group [$F(1,38) = 45.44$, $p < .01$, $\eta_p^2 = .54$], a main effect of condition [$F(1,38) = 57.33$, $p < .01$, $\eta_p^2 = .60$] but no interaction effect [$F(1,38) = .15$, $p = .70$, $\eta_p^2 < .01$]. Analyses on response accuracy demonstrated a main effect of group [$F(1,38) = 23.80$, $p < .01$, $\eta_p^2 = .39$], a main effect of condition [$F(1,38) = 25.50$, $p < .01$, $\eta_p^2 = .40$] and the interaction effect was also significant [$F(1,38) = 4.63$, $p <$

.05, η_p^2 = .11]. These analyses indicate a deficit in inhibitory abilities in normal aging for the saccadic task, taking form of a decrease in response accuracy.

[Insert Table 2 near here]

Go/no-go task. Means of median RTs for correct responses for both conditions and accuracy of responses for no-go stimuli are presented in Table 2. RTs analyses demonstrated a main effect of group [$F(1,38) = 14.40$, $p < .01$, $\eta_p^2 = .27$], a main effect of condition [$F(1,38) = 350.84$, $p < .01$, $\eta_p^2 = .90$] but no significant interaction effect [$F(1,38) = .44$, $p = .51$, $\eta_p^2 = .01$]. Analyses on response accuracy did not demonstrate a significant difference between the two group [$t(38) = -.57$, $p = .57$, $d = -.18$]. These analyses indicate preserved inhibition in normal aging for the go/no-go task.

Motor Simon task. Means of median RTs for correct responses and response accuracy for both conditions (habituation and inhibition) are presented in Table 2. RTs analyses demonstrated a main effect of group [$F(1,38) = 61.60$, $p < .01$, $\eta_p^2 = .62$], a main effect of condition [$F(1,38) = 120.58$, $p < .01$, $\eta_p^2 = .76$] and a significant interaction effect [$F(1,38) = 32.33$, $p < .01$, $\eta_p^2 = .46$], indicating a larger interference effect in normal aging. Analysis of response accuracy demonstrated a main effect of stimuli type [$F(1,38) = 18.13$, $p < .01$; $\eta_p^2 = .32$] but the main effect of group [$F(1,38) = .23$, $p = .63$, $\eta_p^2 < .01$] and the interaction effect [$F(1,38) = 1.60$, $p = .21$, $\eta_p^2 = .04$] were not significant. These analyses indicate a deficit in inhibitory abilities for the motor Simon task in normal aging, taking form of a slowing down of RTs.

Stop Signal task. Means of median RTs for correct responses for both conditions and response accuracy for stop stimuli are presented in Table 2. RTs analyses demonstrated a main effect of group [$F(1,38) = 63.85$, $p < .01$, $\eta_p^2 = .63$], a main effect of condition [$F(1,38) = 33.20$, $p < .01$, $\eta_p^2 = .47$] and a significant interaction effect [$F(1,38) = 10.69$, $p < .01$, $\eta_p^2 = .22$], indicating a larger slowing down of RTs in the inhibition condition compared to the habituation condition for the elderly participants. Analyses on response accuracy did not demonstrate a significant difference between the

two groups [$t(38) = -.23$, $p = .82$, $d = -.07$]. These analyses indicate a deficit in inhibitory abilities for the stop signal task in normal aging, taking form of a slowing down of RTs.

Discussion

The exploration of perceptual and motor inhibitory abilities in normal aging showed results that are in agreement with those previously observed in the literature. Indeed, with regard to perceptual tasks, we observed impaired interference on the Stroop and perceptual Simon tasks, while interference resolution on the negative priming and flanker tasks was preserved. Similarly, previous studies demonstrated lower performance in older than young subjects on the Stroop (Andres, et al., 2008; Belleville, Rouleau, & Van der Linden, 2006; Spieler, et al., 1996) and perceptual Simon tasks (Germain & Collette, 2008), and a normal performance on negative priming (Andres, et al., 2008; Gamboz, et al., 2002) and flanker tasks (Collette, Germain, et al., 2009; Fernandez-Duque & Black, 2006). With regard to motor inhibitory tasks, older participants showed preserved performance only for the go/no-go task, as previously reported by Nielson et al. (2002). We indeed observed in the aging group slower RTs for the motor Simon and stop-signal tasks, and lower accuracy for the saccadic task. Again, these results are in agreement with those previously reported in the literature (e.g., Butler, et al., 1999; Eenshuistra, Ridderinkhof, & van der Molen, 2004; Germain & Collette, 2008; Kramer, et al., 1994; May & Hasher, 1998). These results confirm that not all aspects of inhibitory functioning are impaired in normal aging. The deficits observed consist of a slowing down of the response to produce (except for the saccadic task where decreased accuracy is observed) and affect both the resistance to interference from ***prepotent*** perceptual stimuli and the suppression of prepotent motor responses.

Study 2. The effect of Alzheimer's disease on perceptual and motor inhibition

Methods

Participants

Thirty-two adults volunteered to participate in this study. The 16 normal elderly subjects (7 men and 9 women) had an average age of 75.6 years (SD = 10.6; range: 57-89). Similarly to Study 1, all healthy older adults were involved in leisure and/or voluntary work activities and lived

independently in their own house. Subjects with medical disorders, neurological disorders, psychiatric disorders or medication/substance histories that could affect cognitive functions were excluded from the study. All subjects had normal or corrected to normal vision and audition. No subject reported abnormal colour vision. A total of 16 patients attending the Day Care Center for Memory Disorders in Older People (CHU Liège) also participated in this study. The patients (7 men and 9 women) met the NINCDS-ADRDA criteria for probable Alzheimer's disease (McKhann et al., 1984) and suffered from Alzheimer's disease at a mild stage. All patients had suffered from progressive worsening of memory abilities for at least 6 months. The diagnosis of AD was based on general medical, neurological and neuropsychological examination, with neuroimaging as a biomarker. Structural neuroimaging showed only slight atrophy or mild leukoaraiosis. All patients had a score superior to 21 on the MMSE. Patients had an average age of 75.3 years (SD = 10.3; range: 56-87). No patients suffered from any other medical or neurological condition nor did they take medication that would be likely to adversely affect cognitive performance. They were able to hear and see adequately and follow instructions. No AD patient reported abnormal colour vision. The normal elderly subjects were matched as accurately as possible for age, sex and sociocultural level to the AD patients. These control subjects did not differ from AD patients according to age [$t(30) = -.08$, $p = .93$, $d = -.03$] or education level [$t(30) = .17$, $p = .86$, $d = .06$; AD patients: 10.9 years of education ± 2.0; control subjects: 10.8 years of education ± 2.1]. The elderly participants and AD patients were also administered the Mattis Dementia Rating Scale (Mattis, 1973). All control subjects had a total score superior to 123 on this scale. Overall performance on the Mattis dementia rating scale was significantly lower for AD patients than for control subjects [$t(30) = -4.80$, $p < .01$, $d = -1.7$; AD patients: 122.9 ± 10.5; control subjects: 137.6 ± 6.2].

Procedure

The tasks used in this study were similar to the ones used in Study 1, with the exception of the Mill-Hill Vocabulary Scale which was not administered. Two different orders of administration were used. The first order was similar to the one of Study 1: Stroop task, stop-signal task, perceptual and motor Simon task, go/no-go task, flanker tasks, saccadic task, Mattis Dementia Rating Scale. The tasks were

administered in reverse sequence for the second order. Half of the participants of each group carried out the tasks in each order. Statistical analyses were similar to those performed in Study 1.

Results

Perceptual inhibition

Stroop task. Means of median response times (RTs) for correct responses and response accuracy for the three critical types of items (I : interferent items, I- : negatively primed interferent items, N : neutral items) are presented in Table 1. Analyses on RTs for the interference effect demonstrated a main effect of group [$F(1,30) = 14.43$, $p < .01$; $\eta_p^2 = .32$], a main effect of stimuli type [$F(1,30) = 162.92$, $p < .01$, $\eta_p^2 = .84$], but the interaction effect was not significant [$F(1,30) = 1.43$, $p = .24$, $\eta_p^2 = .05$]. Analyses on response accuracy for the interference effect demonstrated a main effect of group [$F(1,30) = 7.66$, $p < .01$, $\eta_p^2 = .20$], a main effect of stimuli type [$F(1,30) = 22.73$, $p < .01$; $\eta_p^2 = .43$], and the interaction effect was also significant [$F(1,30) = 14.30$, $p < .01$, $\eta_p^2 = .32$]. These analyses indicate a deficit in inhibitory abilities for the interference effect of the Stroop task in AD, taking form of a decrease in response accuracy.

Analyses on RTs for the negative priming effect demonstrated a main effect of group [$F(1,30) = 13.68$, $p < .01$; $\eta_p^2 = .31$], a main effect of stimuli type [$F(1,30) = 20.55$, $p < .01$, $\eta_p^2 = .31$], and a nearly significant interaction effect [$F(1,30) = 3.74$, $p = .06$, $\eta_p^2 = .11$], indicating the tendency for a larger negative priming effect in AD patients than in normal elderly subjects. Analyses on response accuracy for the negative priming effect demonstrated a main effect of group [$F(1,30) = 11.99$, $p < .01$, $\eta_p^2 = .29$], but the main effect of stimuli type [$F(1,30) = .13$, $p = .72$; $\eta_p^2 < .01$], and the interaction effect [$F(1,30) = 1.35$, $p = .25$, $\eta_p^2 = .04$] were not significant. These results can be tentatively interpreted as indicative of a preserved negative priming effect in AD.

Perceptual Simon Task. Means of median response times (RTs) for correct responses and response accuracy for the neutral stimuli and interferent stimuli of the inhibition condition are presented in Table 1. RTs analyses did not demonstrate a main effect of group [$F(1,30) = 3.40$, $p = .08$, $\eta_p^2 = .10$], but the main effect of stimuli type [$F(1,30) = 33.79$, $p < .01$, $\eta_p^2 = .53$] and the interaction effect

[$F(1,30) = 7.71$, $p < .01$, $\eta_p^2 = .20$] were both significant, indicating a larger interference effect in AD patients than in normal elderly subjects. Analyses on response accuracy demonstrated a main effect of group [$F(1,30) = 8.30$, $p < .01$; $\eta_p^2 = .22$] and a main effect of stimuli type [$F(1,30) = 10.23$, $p < .01$, $\eta_p^2 = .25$], but the interaction effect was not significant [$F(1,30) = 1.35$, $p = .25$, $\eta_p^2 = .04$]. These analyses indicate a deficit in inhibitory abilities for the perceptual Simon task in AD, taking form of a slowing down of RTs.

Flanker task. Means of median response times (RTs) for correct responses and response accuracy for the neutral and interferent stimuli are presented in Table 1. RTs analysis demonstrated a main effect of group [$F(1,30) = 5.89$, $p < .05$, $\eta_p^2 = .16$], a main effect of stimuli type [$F(1,30) = 12.19$, $p < .01$, $\eta_p^2 = .29$], but the interaction effect was not significant [$F(1,30) = 2.98$, $p = .09$, $\eta_p^2 = .09$]. Response accuracy analyses demonstrated a main effect of group [$F(1,30) = 9.36$, $p < .01$; $\eta_p^2 = .24$], but no main effect of stimuli type [$F(1,30) = .10$, $p = .75$, $\eta_p^2 < .01$], and the interaction effect was not significant either [$F(1,30) = 1.37$, $p = .25$, $\eta_p^2 = .04$]. These analyses indicate preserved inhibitory performance in AD for the flanker task.

Motor inhibition

Saccadic task. Means of median response times (RTs) for correct responses and response accuracy for the pro-saccade and anti-saccade conditions are presented in Table 2. *Although the performance of AD patients in the antisaccade condition overlaps the chance level, we consider that they correctly understood the rationale of the task. Indeed, the patients performed above chance level in the prosaccade condition that was administered first and was associated to similar task instructions. Moreover, AD patients were able to explain the rationale of the task during practice trials*. *However, the RTs analysis on accurate responses was not performed since we cannot rule out the possibility that "correct" trials are due to guessing and not to efficient inhibition.* Analyses on response accuracy demonstrated a main effect of group [$F(1,30) = 9.83$, $p < .01$, $\eta_p^2 = .25$], a main effect of condition [$F(1,30) = 54.04$, $p < .01$, $\eta_p^2 = .64$], but the interaction effect was not significant [$F(1,30) = .48$, $p = .49$, $\eta_p^2 = .02$]. These analyses indicate preserved inhibitory performance for the saccadic task in AD.

Go/no-go task. Means of median response times (RTs) for correct responses for both conditions and accuracy of responses for no-go stimuli are presented in Table 2. RTs analyses demonstrated a main effect of group [$F(1,30) = 4.58$, $p < .05$, $\eta_p^2 = .13$], a main effect of condition [$F(1,30) = 66.23$, $p < .01$, $\eta_p^2 = .69$], but no significant interaction effect [$F(1,30) < .01$, $p = .96$, $\eta_p^2 < .01$]. Analyses on response accuracy did not demonstrate a significant difference between the two group [$t(30) < -.01$, $p > .99$, $d < -.01$]. These analyses indicate preserved inhibition in AD for the go/no-go task.

Motor Simon task. Mean response times (RTs) for correct responses and response accuracy for both conditions are presented in Table 2. RTs analyses demonstrated a main effect of stimuli type [$F(1,30) = 184.02$, $p < .01$, $\eta_p^2 = .86$], but the main effect of group [$F(1,30) = 3.25$, $p = .08$, $\eta_p^2 = .10$] and the interaction effect [$F(1,30) = .02$, $p = .90$, $\eta_p^2 < .01$] were not significant. Analyses on response accuracy demonstrated a main effect of group [$F(1,30) = 7.51$, $p < .05$; $\eta_p^2 = .20$], a main effect of stimuli type [$F(1,30) = 14.39$, $p < .01$, $\eta_p^2 = .32$], and the interaction effect was also significant [$F(1,30) = 4.95$, $p < .05$, $\eta_p^2 = .14$]. These analyses indicate a deficit in inhibitory abilities in AD for the motor Simon task, taking form of a decrease in response accuracy.

Stop Signal task. Means of median response times (RTs) for correct responses for both conditions and response accuracy for stop stimuli are presented in Table 2. RTs analyses did not demonstrate a main effect of group [$F(1,30) = .76$, $p = .39$, $\eta_p^2 = .02$], but the main effect of condition [$F(1,30) = 32.69$, $p < .01$, $\eta_p^2 = .52$] and the interaction effect [$F(1,30) = 6.27$, $p < .05$, $\eta_p^2 = .17$] were both significant, indicating that normal elderly participant slowed significantly more their responses in the inhibition condition compared to the habituation condition than AD patients. On the other side, analyses on response accuracy demonstrated that AD patients made significantly more stop errors than normal elderly subjects [$t(30) = -4.34$, $p < .01$, $d = -1.53$]. An ANCOVA was performed to determine whether the deficit in response accuracy for AD patients remained significant after controlling for the difference in slowing down between the two groups. An index of slowing down was calculated for each subject: [(mean of median RT of the control condition – mean of median RT of the stop-signal condition) / (mean of median RT of the control condition + mean of median RT of the stop-signal condition)]. When controlling for this index, the difference in stop responses accuracy between the

two groups remained significant [$F(1,29) = 10.11$; $p < .01$; $\eta_p^2 = .26$]. These analyses indicate a deficit in inhibitory abilities in AD for the stop signal task, taking form of a decrease in response accuracy.

Discussion

The exploration of perceptual inhibitory abilities in mild Alzheimer's disease showed a preserved performance for the negative priming and flanker tasks only. The presence of preserved negative priming is in agreement with the results of Langley, Overmier, Knopman and Prod'Homme (1998). However, previous results reported for the flanker task were mitigated since slower RTs were indeed observed by Fernandez-Duque and Black (2006) but not by Collette, Schmidt et al. (2009) that only reported a decreased accuracy on this task. With regard to the Stroop task, more errors were observed in the interference condition for AD patients. Such a result was previously reported (Amieva, et al., 2002; Bondi et al., 2002) but, contrary to the present study, was associated with a slowing down. Finally, to the best of our knowledge, no study previously administered the perceptual Simon task to AD patients. With regard to motor inhibition, AD patients had a performance similar to that of healthy older participants on the saccadic and go/no-go tasks. A preserved performance was also observed at several occasions for the go/no-go task in AD (Amieva, et al., 2002; Collette, et al., 2007; Kensinger, Shearer, Locascio, Growdon, & Corkin, 2003). However, previous studies that explored control of saccadic eye movements seems to indicate impaired abilities (Amieva, et al., 2004). As for the perceptual Simon task, no study previously administered the motor Simon task to AD patients. Finally, impaired performance (as assessed by response accuracy) was observed in our group of patients for the stop-signal task, although Amieva et al. (2002) reported no deficit on this task. These results[8] confirm that not all aspects of inhibitory functioning are impaired in mild Alzheimer's disease. The deficits observed consist in the production of more errors than observed in normal aging (except for the

[8] Results obtained with our battery of tasks globally replicate those previously reported in the literature, even if some discrepancies were sometimes observed (e.g., the stop-signal task in AD patients). Although the discussion of these discrepancies is outside the topic of the present paper, we can suppose that the use of slightly different procedures or sampling AD population at different stages of the disease are probable explanations (for a discussion of discrepant results between studies assessing the Stroop interference and negative priming, see for example Hogge, et al., 2008)

perceptual Simon task where only a slowing down is observed) and affect both the resistance to interference from proponent perceptual stimuli and the suppression of prepotent motor responses.

General discussion

It is now widely accepted that inhibition is not a unitary construct. In that context, we assessed the performances of young adults, normal older participants and mild AD patients on a series of inhibitory measures in order to determine whether the proposal of independence between perceptual and motor inhibitory processes (Dempster & Corkill, 1999a, 1999b; Nassauer & Halperin, 2003) may apply to these two aging populations. A summary of preserved and impaired performances on tasks administrated in normal aging and mild Alzheimer's disease is presented in Table 3.

[Insert Table 3 near here]

As previously discussed, no specific impairment of perceptual or motor inhibition was demonstrated in either group. Indeed, two of the three preserved tasks in normal aging were measures of perceptual inhibition, and two of the four preserved tasks in AD patients were measure of motor inhibition. Those results cannot be considered as being in agreement with the distinction previously proposed between perceptual and motor inhibitory processes (Dempster & Corkill, 1999a, 1999b).

Interestingly, the comparison of performance between young and older participants (Study 1) and between older participants and mild Alzheimer's disease (Study 2) indicates that the three same tasks (the negative priming, flanker and go/no-go tasks) are completely spared in normal aging and Alzheimer's disease (no between-group differences for RTs and response accuracy; see Table 3). The characteristics of tasks preserved in the two populations led us to interpret the pattern of inhibitory performance showed by older participants and AD patients in favor of Roberts' proposal (Roberts, et al., 1994; Roberts & Pennington, 1996) *directly relating* working memory capacity and inhibitory efficiency. Indeed, these authors proposed that successful inhibition depends on (1) the strength of the automatism of the action to be inhibited, (2) the working memory demand of the task and (3) the working memory resources available for the task's requirements. Accordingly, tasks that are less

demanding in terms of general cognitive resources and/or controlled processes will be easier to perform.

In agreement with that theory, tasks that are preserved in our healthy participants and Alzheimer's patients groups are less demanding in terms of general cognitive resources and/or controlled processes. Indeed, negative priming is often referenced as an automatic inhibition effect (e.g., Andres, et al., 2008; Houghton & Tipper, 1994) that does not rely on controlled processing, and a recent study demonstrated with factorial analysis that inhibitory performance on the flanker task loaded heavily on a factor reflecting automatic inhibition (Collette, Germain, et al., 2009). It thus seems that the resolution of interference in these two tasks relies mostly on automatic processes, requiring few cognitive resources. Consequently, the additional cognitive load associated *with* the processing of interferent stimuli was probably extremely small, which might explain the similar interference effect in young and older participants as well as in healthy controls and Alzheimer patients. Finally, the go/no-go task we used can be considered as recruiting few working memory resources. Indeed, only one mapping between stimulus and response was required and a variable inter-stimulus interval was used in the habituation condition, which did not favor the creation of a strong stimulus-response link necessitating extensive cognitive resources to be inhibited in the no-go trials (Wodka, Simmonds, Mahone, & Mostofsky, 2009). Moreover, it is well known that normal aging is characterized by a general decrease in working memory capacity (e.g., Gregoire & Van der Linden, 1997; Orsini, Chiacchio, Cinque, Cocchiaro, & et al., 1986) and that the various cognitive deficits presented by AD patients in the early stages of the disease are characterized by an impairment of controlled processes associated to a preservation of the automatic ones (Adam, Van der Linden, Collette, Lemauvais, & Salmon, 2005; Fabrigoule et al., 1998; Salthouse & Becker, 1998).

Additionally, observation of Table 3 reveals that the impairments observed in normal aging and AD do not overlap in term of RTs and response accuracy. Indeed, most of the impairments in normal aging consist of a slowing down in RTs latency, whereas, in the AD group, they mostly consist of deficits in response accuracy without additional interactive effect on RTs. This pattern of results suggests that inhibitory abilities take more time to be put in place but are still relatively effective in normal aging, whereas a real breakdown of inhibitory functioning occurs in mild AD. Accordingly,

Bélanger, Belleville and Gauthier (2010) suggested, in a recent study using the Stroop task, that goal maintenance is only partially impaired with age (as older adults need more time to re-implement goal appropriate strategies but do not produce more errors than their younger counterparts) while goal maintenance was frequently lost in AD patients (as attested by the increased error rate). As a whole, these results and those obtained in the present study seem to indicate that inhibitory deficits are qualitatively different in these two populations in the sense that a less severe impairment in normal aging may have a selective impact on RTs, whereas only more severe deficits would additionally impair response accuracy, such as what is shown *in* AD.

To conclude, this study revealed that the patterns of inhibitory deficits in normal aging and mild Alzheimer's disease do not reflect a specific impairment of perceptual or motor inhibitory processes and rather suggest that other inhibitory frameworks might provide better insights about performance showed by the two groups. We have proposed that a decrease in cognitive resources available in working memory and impairment of cognitive controlled processes could explain inhibitory performance in normal aging and Alzheimer's disease respectively. We have also proposed that a loss of goal maintenance could explain the low response accuracy of mild AD patients. However, these interpretations were proposed a posteriori and must be confirmed in future studies specifically build up to explore these proposals. Finally, from a clinical viewpoint, the presence of both preserved and impaired performance on perceptual and motor inhibitory tasks indicate the necessity to explore inhibitory abilities with tasks assessing various aspects of inhibition in aging populations in order to evidence the presence of inhibitory deficits.

Conflict of interest

The authors of the article have no financial or personal conflict of interest relating to this work.

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Table 1. Means of median response times for correctly performed items and mean response accuracy for perceptual inhibition tasks.

	Study 1		**Study 2**	
	Young subjects	**Elderly subjects**	**Matched elderly subjects**	**Alzheimer patients**
Stroop task				
N RT	681 (84)	783 (112)	683 (118)	1030 (414)
I RT	841 (116)	***1062 (160)***	1029 (319)	1675 (768)
I- RT	893 (130)	1131 (150)	1102 (365)	2087 (1408)
N%	99.71 (1.27)	98.68 (2.99)	100 (0.00)	95.49 (11.51)
I %	97.51 (3.69)	96.83 (2.53)	98.96 (1.72)	***86.46 (14.23)***
I- %	97.20 (5.33)	96.84 (4.58)	97.57 (3.50)	87.19 (12.58)
Perceptual Simon				
Neutral RT	474 (94)	653 (92)	739 (148)	885 (336)
Interferent RT	502 (94)	***719 (99)***	774 (146)	***1042 (498)***
Neutral %	98.50 (3.48)	97.50 (3.80)	93.44 (8.70)	78.59 (21.76)
Interferent %	95.50 (6.10)	94.00 (6.46)	89.06 (12.04)	69.22 (24.76)
Flanker task				
Neutral RT	630 (118)	911 (262)	825 (198)	1043 (409)
Interferent RT	659 (98)	925 (209)	863 (183)	1215 (511)
Neutral %	98.54 (3.39)	93.96 (10.51)	95.31 (5.67)	76.82 (27.13)
Interferent %	96.25 (5.39)	91.46 (11.51)	96.35 (4.78)	75.00 (24.77)

Note: RT: response time. %: accuracy. N: neutral items. I: interferent items. I-: negatively primed interferent items. Numbers in brackets represents standard deviation of the mean. RTs are presented in ms and were log transformed for statistical analyses. Bold italics show impaired performance in elderly versus young participants and in mild AD patients compared to elderly controls.

Table 2. Means of median response times for correctly performed items and mean response accuracy for motor inhibition tasks.

	Study 1		**Study 2**	
	Young subjects	**Elderly subjects**	**Matched elderly subjects**	**Alzheimer patients**
Saccadic Task				
Pro-saccade RT	385 (85)	633 (191)	735 (209)	826 (328)
Anti-saccade RT	458 (108)	749 (165)	880 (288)	875 (330)
Pro-saccade %	97.92 (3.24)	83.85 (15.32)	75.52 (21.28)	55.60 (24.14)
Anti-saccade %	91.46 (8.08)	***67.81 (22.03)***	42.32 (17.29)	28.13 (12.55)
Go/no-go				
Habituation RT	306 (79)	389 (105)	414 (177)	517 (234)
Inhibition RT	482 (70)	588 (84)	602 (74)	742 (160)
No-go %	97.25 (3.8)	96.25 (6.86)	95.94 (3.75)	95.94 (4.55)
Motor Simon				
Habituation RT	304 (41)	404 (94)	405 (51)	527 (230)
Inhibition RT	349 (63)	***611 (135)***	647 (138)	836 (403)
Habituation %	99.38 (1.11)	99.75 (0.77)	98.84 (0.62)	97.81 (2.56)
Inhibition %	97.75 (3.02)	96.75 (4.22)	95.94 (4.64)	***82.81 (20.37)***
Stop Signal				
Habituation RT	637 (78)	834 (118)	840 (103)	987 (271)
Inhibition RT	697 (161)	***1092 (208)***	1112 (215)	1079 (203)
Stop %	80.95 (19.27)	82.38 (20.36)	84.61 (10.68)	***59.99 (20.01)***

Note: RT: response time. %: accuracy. Numbers in brackets represents standard deviation of the mean. RTs are presented in ms and were log transformed for statistical analyses. Bold italics show impaired performance in elderly versus young participants and in mild AD patients compared to elderly controls.

Table 3. Summary of the pattern of preserved/impaired performance of healthy older participants and mild AD patients on perceptual and motor inhibitory tasks

	Study 1 Normal aging Vs. Young adults		**Study 2** AD patients Vs. Normal aging	
	RT	**%**	**RT**	**%**
Perceptual inhibition				
Stroop interference	Impaired	Preserved	No more impaired	Impaired
Negative priming	Preserved	Preserved	Preserved	Preserved
Perceptual Simon	Impaired	Preserved	Impaired	Preserved
Flanker task	Preserved	Preserved	Preserved	Preserved
Motor inhibition				
Saccadic task	Preserved	Impaired	-	No more impaired
Go/No-go	Preserved	Preserved	Preserved	Preserved
Motor Simon	Impaired	Preserved	No more impaired	Impaired
Stop signal task	Impaired	Preserved	No more impaired	Impaired

Note: "No more impaired" in the AD group for inhibitory measures that are impaired in normal aging should be read as "No more impaired than in normal older participants".

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