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Use of the Hayling task to measure inhibition of prepotent responses in normal aging and Alzheimer's disease

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Keywords: Executive functions; Inhibition; Alzheimer's disease; Hayling test

Abstract

This study measures the effect of Alzheimer's disease (AD) and normal aging on the inhibition of prepotent responses. AD patients, normal aged controls, and young subjects were tested with the Hayling task, which measures the ability to inhibit a semantically constrained response, and with the Stroop procedure. AD patients showed a severe deficit in both error rates and response time on the Hayling task. Inhibition was also impaired on the Stroop procedure, both when using raw performance and when using an inhibition score that controlled for reading and naming speed. Normal aged participants showed modest impairment relative to young controls on both tests. Examination of individual performance in AD patients indicated that the impairment was found in most patients on the Hayling test but in only a subgroup of patients on the Stroop test.

Introduction

Alzheimer's disease (AD) is a degenerative disease that affects a wide range of cognitive functions, including memory, attention, and language. Whereas the majority of clinical accounts of early AD propose that memory functions are affected the earliest, there is increasing evidence to suggest that executive functions are also impaired very early in the disease process and that this impairment could have a significant impact on patients' autonomy (Amieva, Phillips, Della Sella, & Henry, 2004; Perry & Hodges, 1999).

The supervisory attentional system (SAS) is a major model of executive functions (Norman & Shallice, 1986; Shallice, 1988). The model is based on the proposition that while most actions are performed automatically, novel, demanding, and conflicting actions require involvement of

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the SAS. This system is thought to act as an attentional controller by modulating the pattern of activation of action schemas with inhibitory processes. On this view, suppression of irrelevant responses is under the control of the SAS. Cognitive inhibition is defined as a mechanism that actively suppresses distracting information (Hamm & Hasher, 1992) or properties of the distractors, which are in direct competition with the information relevant to the subject's goals (Tipper, Weaver, & Houghton, 1994). Within this view, inhibition is a flexible mechanism, adaptable to the nature of both the task and distractors.

The distractibility of AD patients and their tendency to make numerous intrusion errors in memory and retrieval tasks suggests that deficient inhibitory processes may con- tribute largely to their cognitive impairments. Direct measures of inhibition tend to support this view. Sullivan, Faust, and Balota (1995) measured inhibition in this clinical population using the negative priming paradigm. In their procedure, subjects were shown two overlapping objects, one red and the other green and subjects were instructed to name the red object as fast as possible and to ignore the green one. Response time increased when the object serving as a distractor in one trial was used as a target in the very next trial. This *negative priming effect* suggests that the distractor was first inhibited and thus took longer to activate in the next trial. The authors found impaired inhibition in AD patients using this negative priming paradigm. The Stroop task has also been used to assess inhibition in AD and normal aging. The results on this task are also consistent with an inhibitory breakdown in normal aging and with an amplification of this breakdown in AD (Spieler, Balota, & Faust, 1996). Amieva and collaborators (2002) used a set of computerized tasks in testing the hypothesis that there are different subcomponents of inhibition. These authors investigated whether there was a selective inhibition deficit in this disease or whether it encompassed the whole range of inhibition processes. The results indicated that persons with AD failed to exhibit the negative priming effect and were impaired on the Stroop task. However, they performed normally or at a slightly impaired level on tasks of motor inhibition (go-no go and Stop signal paradigms, respectively). These findings suggest that the inhibition deficit in AD is not a general impairment, but is instead restricted to specific components.

Based on the research described above, there are indications of inhibition deficits in AD patients. However, the extent of these deficits and their relation to the impairments found in normal aging remain to be further understood. Most importantly, both the negative priming and Stroop tasks have been criticized as "pure" measures of inhibition. For example, the interference portion of the Stroop task has been interpreted as reflecting the resolution of a conflict between word reading and color naming and its impairment in AD has been attributed to semantic deficits as well as slowed speed of verbal processing based on a principal components analysis (Bondi et al., 2002). Similarly, a number of authors have argued that the negative priming task indexes episodic retrieval processes (for a review, see Fox, 1995). As a result, other types of inhibition tasks need to be used in AD and additional studies that combine more than one inhibitory task are warranted to confirm that the impaired performance shown by AD patients on these tasks reflects executive inhibition deficits.

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Of particular interest in this regard is the use of the Hay- ling test to study inhibition in frontal lobe injured patients (Burgess & Shallice, 1996). In this task, subjects are asked to complete, as fast as possible, sentences in which the last word is missing. The sentences provide a semantically constrained context such that they are selected to rapidly and automatically induce a particular last word (e.g., 'Most cats see well at…?'- night -). In the first condition, subjects are asked to complete the sentences properly, thus reflecting the initiation of a semantically supported automatic response. In the second condition, subjects are asked to refrain from using the automatically activated (or common-sensical) word and to complete the sentence with an entirely unrelated item. This task produces an inhibition of the prepotent response yielded by semantic activation, as subjects have to inhibit the activated word and its semantic associates to perform the task correctly. It has been shown that frontal lobe lesions impede performance on the inhibition section of the Hayling task (Burgess & Shallice, 1996) and that response inhibition in that task is associated with increased activation in a network of left prefrontal areas (Collette et al., 2001). This confirms the executive nature of the Hayling task and its potential for measuring response inhibition in AD. There has been only a single study on the Hayling task in persons with AD and the results indicated a significant impairment in this group (Collette, Van der Lin- den, & Salmon, 1999). This finding has potential implications at the clinical level, as clinical versions of this test are being developed and distributed (Burgess & Shallice, 1997). Considering the potential application of the Hayling test as a diagnostic tool, additional studies are warranted to assess the degree to which individuals with AD are impaired on the task, the sensitivity to the task at the individual level, the specificity relative to the effect of normal aging, and the relation between this task and classical measures of inhibition. These are elements that were addressed in the present study.

The goal of the present study was to assess inhibition in participants with AD as measured by performance on the Hayling test. Participants were also administered the Stroop task, which is typically used as an index of inhibition in clinical practice, but has been criticized as a poor measure of genuine inhibition in AD.

Semantic deficits and slowing have been proposed to account for the impairment that persons with AD experience in the interference portion of the Stroop task. To control for these potential contributors, we used an inhibition score that takes into account the performance on the naming and reading portions of the Stroop by subtracting from the interference portion of the test the time that the subjects took to perform these portions of the task. For similar reasons, the performance on the first and automatic section of the Hayling test, which measures the ability to complete the test by providing the appropriate word, can be used to examine word finding and/or speed deficits.

An additional goal of this study was to compare the pat- tern of inhibition deficits in persons with AD to those resulting from normal aging. The cognitive impairments associated with normal aging are frequently interpreted as resulting from a decline in functions associated with the frontal lobes (Moscovitch & Winocur, 1996; West, 1996). From a clinical point of view, a major difficulty in the diagnosis of AD is to distinguish its early manifestations from normal age-related cognitive decline. Thus, it is important to shed light on the specific nature of AD-related inhibition deficit as compared

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to normal aging. To assess the effect of normal aging we compared the performance of the older healthy participants to that of young participants.

Finally, we were interested in examining the individual pattern of performance in AD patients. AD is often classified as a heterogeneous disease (Habib et al., 1991; Martin and collaborators, 1986; Neary and collaborators, 1986), leading to different cognitive impairments across patients. However, it is crucial to report and qualify this potential heterogeneity because not all components appear to have similar levels of heterogeneity. For example, our previous studies have shown that contrary to the above view, the working memory deficit is remarkably homogeneous even in very mild AD patients (Belleville, Peretz, & Malenfant, 1996; Belleville, Rouleau, Van der Linden, & Collette, 2003). In this context, examination of individual profiles is likely to provide important information regarding the pervasiveness of the inhibition deficit in AD. It may also shed light on the way inhibition tasks should be used in clinical practice. Tasks on which impairment is highly homogeneous are likely to be powerful diagnostic markers of the disease. In turn, tasks on which performance has a marked heterogeneity are likely to be qualifiers of differential impairment and potential markers for patient subtyping and for the development of differential modes of intervention. Thus, examination of individual differences was conducted in this study by deriving individual *Z*-scores in patients with AD.

Methods

PARTICIPANTS

Thirty-six participants took part in the experiment: 12 young, 12 old, and 12 patients suffering from AD. The young adults (6 males and 6 females) were between 19 and 30 years of age ($M = 22.0$), and had a mean of 13.8 years of education ($SD = 1.7$). The older adults (4 males and 8 females) were between 68 and 83 years of age ($M = 72.7$) and had a mean of 11.0 years of education ($SD = 2.0$). The AD patients were between 64 and 85 years of age ($M = 72.5$; $SD = .99$) and had an average of 10.1 years of education ($SD = 1.9$). Patients were matched with their normal aged controls on age, sex, education, and where possible, profession. The difference in the formal education and mean age between the normal elderly and AD participants was not significant, $t(11) = 2.11$, $p = .0586$, and $t(11) = 0.39$, $p = .7195$, respectively. All participants were French-speaking. Young and normal aged participants were drawn from a pool of volunteers. They had no history of neurological disease, psychiatric disorder, or general anaesthesia in the past year. They had not used medication known to affect memory or other cognitive functions. AD patients were recruited from three different hospitals in Liège and Brussels (Belgium) and in Montreal (Canada). All participants reported normal hearing and had normal or corrected vision.

The patients were diagnosed as suffering from AD, according to the NINCDS-ADRDA criteria (McKhann and collaborators, 1984), (10 probable and 2 possible diagnosis). The severity of their disease ranged from mild to moderate, according to the Clinical Dementia Rating scale (CDR) (Hughes and collaborators, 1982). The patients underwent extensive medical and neurological

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examinations to ensure the absence of any other major neurological conditions. Furthermore, the majority of patients were given a neuroradiological examination, including nuclear magnetic resonance imaging.

Elderly control participants and AD patients completed a battery of neuropsychological tests. These tests included (1) the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975), which is used to screen for major cognitive defects, (2) the Mattis Dementia Rating Scale (Mattis, 1976), which estimates the integrity of attention, initiation, construction, concepts, and memory, (3) two subtests from the Weschler Memory Scale (logical memory and design memory) (Wechsler, 1945), and (4) the French-version of the Mill Hill Vocabulary Test (Gérard, 1983), a multiple- choice synonym test reflecting the general verbal level of subjects. AD patients were also tested on additional clinical tests measuring language and executive function. Normal aged subjects included in the study performed normally on this neuropsychological assessment. On the Mattis Dementia Rating Scale, they obtained a mean score of 140.17/144, which is well within normal limits according to the most recent norms (Schmidt and collaborators, 1994). Thus, the elderly subjects included in the control group did not show signs of early dementia. Because the young participants were not at risk for early signs of dementia, they were not tested as extensively as elderly controls. Nevertheless, they did complete the Mill Hill Vocabulary Test and a short- term memory span task of the Batterie d'Évaluation de la Mémoire, Côte-des-Neiges, (Chatelois et al., 1993), on which they performed within the normal range. The main clinical data is summarized in Table 1.

MATERIALS AND PROCEDURE

THE HAYLING TASK

We used an adaptation of the Hayling task reported by Burgess and Shallice (1996). Since, the original version was in English, it was necessary to translate and adapt the sentences for the French language. Thirty sentences for which the final word was missing were selected based on pilot testing. A pilot study was conducted to ensure that the sentences chosen were completed with a similar word by the majority of participants.

Table 1 *- Clinical and demographic characteristics of the participants*

	Young	Older	Alzheimer
Age	22 (3.2)	72.7 (4.6)	72.5 (5.9)
Education	13.8 (1.7)	11 (2.0)	10.1 (2.0)
MMSE (/30)	n/a	28.2 (1.1)	22.9 (2.0)
Mill Hill (/44)	34.4 (5.2)	35.3 (6.7)	31 (4.4)

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In the pilot study, twenty young participants (half of whom were from Quebec and the remaining half from Belgium) were asked to provide the final word for 50 incomplete sentences. Thirty sentences were chosen from this set on the basis of each having been completed by an identical word by all of the participants in the pilot study. Sentences were randomly assigned to either the automatic or inhibition condition. Four additional sentences were used for pre-experimental examples.

There were two conditions (Automatic and Inhibition), for which two different sets of 15 sentences were assigned. In the "Automatic" condition, the experimenter read aloud each sentence to the subject. The participant was told to listen to the sentence and complete it with the appropriate word as quickly as possible. Two practice sentences were initially presented. Response latencies were recorded with a stop-watch, beginning when the last word was pronounced by the examiner and ending when the participant began to respond. Response accuracy was also recorded (see Section 3 for detailed scoring). In the "Inhibition" condition, participants were told to finish the sentence as rapidly as possible with a word that was completely unrelated to it and that was nonsensical in the context of that sentence. Two examples were also given to participants prior to the task. For all trials, if a participant gave an erroneous response (related to the sentence, or the automatically-activated word), the examiner repeated the instructions and told the participant that his or her response was too closely related to the sentence. No time limit was given for responding. However, the majority of responses (whether correct or incorrect) were given within 60 s.

THE STROOP TEST

The task employed was adapted by Golden (1976) and is typically used in clinical settings. Stimuli were presented on three different cards, one for each of three conditions. In the "Word" condition, the words *bleu* (blue), *rouge* (red), and *vert* (green) were written in black ink. In the "Color" condition, sequences of *xxxx* were presented in red, blue, or green ink. In the "Interference" condition, the words *bleu* (blue), *rouge* (red), and *vert* (green) were written in blue, red, or green ink. On this last card, the three color words always differed from the word's ink color (e.g., the word green written in red ink). One hundred stimuli were presented on each card.

Card-conditions were presented in the following order: Word, Color, and Interference. Participants were asked to read aloud as quickly as possible the words on the first card (color names written in black ink) and the ink color of the stimuli on the other two cards (the x's or color names). In the Interference condition, participants had to inhibit the written word to correctly name the ink color, as the two always differed (a Stroop-effect). In this version of the Stroop task, the dependent variable was the number of items read correctly during a 45 s interval. If participants finished prior to the deadline, they were asked to start over from the beginning.

Clinical and experimental testing was completed in a single session that lasted approximately 2 h. The Hayling test was completed first, followed by the Stroop task. Tests were completed in a fixed-order to allow for between-subject comparisons. Breaks were allowed when necessary.

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Results

HAYLING TEST

Two dependent measures were used in the Hayling test: response latency and error rate. The median (in seconds) was calculated for each condition and participant to obtain a response latency score. An average response latency score was then computed based on all responses including errors. In the inhibition condition, responses were scored according to the criteria proposed by Burgess and Shallice (1996). This was done to allow direct comparison with Burgess & Shallice's data collected with frontal lobe patients. According to this scoring system, a 3-point score was obtained in the inhibition condition when the sentence was completed with the word that fit into it. For example, in the sentence "The captain wanted to stay with the sinking?", the response "boat" would yield a score of 3. One point was given when a subject gave an antonym, a semantically related word, a word that made a vague reference to the sentence, an obscenity or another inappropriate word. Participants received zero points when an unrelated response was provided. Considering each type of response separately did not modify the general pattern of findings. We thus chose to pool them together in the form of an error score. In the automatic condition, an error score was computed following the reversed correction criteria: three error points were given when participants gave an unrelated word, one point when the word was semantically connected to the target or semantically relevant to the sentence, and no error point for the target. Thus in both the automatic and inhibition conditions, a larger score was associated with largerimpairment.

As a first step, a 3 (Group) by 2 (Condition) ANOVA was conducted for latencies. Fig. 1 illustrates the time data. The analysis indicated significant effects of Group, F (2, 33) = 21.686, MSE = 0.867, p < .001; Condition, F (1, 33) = 114.782, MSE = .871, p < .001, and a Group by Condition interaction, F (2, 33) = 15.278, MSE = .871, p < .001. Analysis of the interaction revealed that the groups did not differ significantly in the Automatic condition, F (2, 33) = 2.890, MSE = 0.082, p = .07, but differed in the Inhibition condition, F (2, 33) = 19.251, MSE = 1.655, p < .001. Post hoc pairwise comparisons (Sheffe) indicated that this was due to the fact that AD patients were slower than both the elderly (p < .01) and young (p < .001) participants on the inhibition portion of the task. Moreover, elderly persons were slower than their younger counterparts in that condition (p < .05). All participants were affected by the experimental condition, but the effect was larger for AD patients, F (1, 33) = 103.680, MSE = .871, p < .001, than for the normal elderly controls, F(1,33) = 36.034, MSE = .871, p < .001, and young participants, F (1, 33) = 5.624, MSE = .871, p < .05.

A 3 (Group) 2 (Condition) ANOVA was also conducted on error scores (Fig. 2). The analysis revealed a significant effect of Group, F(2,33) = 29.756, MSE = 573.29, p < .001 and Condition, F (1, 33) = 51.753, MSE = 12.176, p < .001. Importantly, the Group by Condition interaction was significant, F(2,33) = 20.352, MSE = 12.176, p < .001. Analysis of the simple effects revealed that the performance of young and elderly persons did not differ in the automatic and inhibition conditions, F(1, 33) = 1.971, MSE = 12.176, p = .170 and F (1, 33) = 2.878, MSE = 12.176, p .099, respectively. However, AD patients were more

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impaired in the inhibition than the automatic condition, F (1, 33) = 87.608, MSE = 2.176, p < .001. Whereas the groups differed in both conditions, the effect was larger in the inhibition, F(2,33)= 28.391, MSE = 27.720, p<.001 than in the automatic F(2, 33) = 9.157, MSE = 3.722, p = .05, conditions.

1.1. Stroop test

The number of words correctly read in the 45 s period is shown in Table 2 for the reading, naming, and interference cards. An "inhibition score" was calculated for each partic- ipant according to the following equation: Interference/ [(Word + Color)/2]. The score evaluates the inhibition eVect by taking into account reading and naming speed. The resulting scores are shown in Table 2. Larger scores corre- spond to better inhibition capacities (or smaller interfer- ence eVect). A one-way ANOVA performed on these scores yielded a signiWcant Group eVect, F (2, 33) 21.995, MSE 0.011, p < .001. Pairwise comparisons using the SheVe test indicated a signiWcant diVerence between youn- ger and older healthy participants, p < 0.05, as well as anFig. 1. Response time in the Hayling test. (dark bars) Automatic condi- tion, (white bars) inhibition condition.

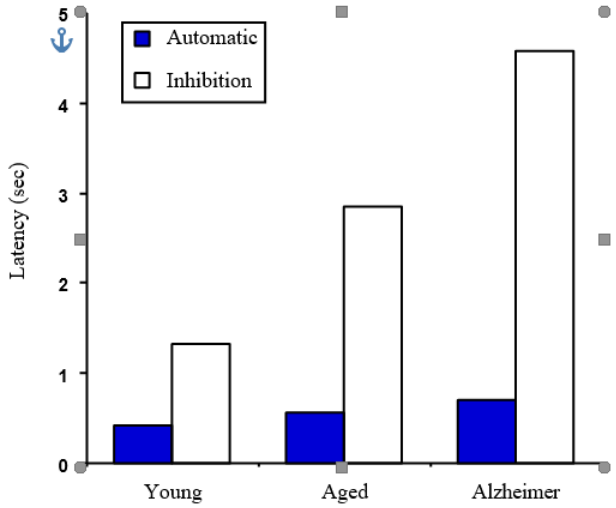

Fig. 1. *Response time in the Hayling test. (dark bars) Automatic condition, (white bars) inhibition condition*

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STROOP TEST

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INDIVIDUAL PROFILES

Table 3 displays individual data for AD patients on the four Stroop variables and on the Hayling error scores. Nor- mal performance was defined as a score that was 1.5 *SD* within the mean of older healthy controls. Performance was considered impaired if it departed from that cutoff (see Table 3 for normalized values of impaired performance in AD participants).

Table 2

Performance on the Stroop task: number of items correctly produced on the reading card, naming card and interference card and inhibition score

	Young	Older	Alzheimer
Reading	116.17 (16.51)	94.25 (18.53)	61.67 (22.8)
Naming	82.17 (11.97)	57.58 (14.71)	29.5 (19.7)
Interference	48.50 (7.18)	27.58 (9.62)	11.17 (12.4)
Inhibition score	494(.07)	365(.11)	.212(.126)

Note: Standard deviations in parenthesis.
Inhibition score = Interference/[(Word + Color)/2]. Note that in all cases, a larger score is associated with better performance.

Table 3

Individual performance on the Stroop and Hayling tests expressed in terms of the number of SD away from matched controls

Patient	Stroop task				Hayling task	
	Reading	Naming	Interference	Inhibition	Automatic	Inhibition
1	N	N	N	N	N	2.3
2	-2.5	-3.2	-2.3	-1.8	N	8.5
3	N	N	-1.6	N	N	11.8
4	-1.7	-1.7	N	N	2.	4.7

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5	-3.8	-3.4	-2.8	-2.8	6.7	8.5
6	-3.4	-3.1	-2.3	N	2.6	8.5
7	N	-1.7	-2.	-2.	N	3.7
8	-1.8	-2.3	-1.9	N	3.2	11.8
9	-3.	-1.8	-2.1	-1.5	N	3.7
10	N	N	N	N	N	3.2
11	N	-2.2	- 2.5	-2.7	N	11.3
12	?	-2.8	-2.3	-2.5	N	N

N stands for normal performance (no more than 1.5 SD away from controls).

On the Stroop test, a large proportion of AD patients were impaired on the interference card (83%). However, 90% of these patients were impaired on the reading and/or naming cards as well. This suggests that in many patients, the impairment on the interference card was partly accounted for by an impairment on the reading and/or naming portion of the task either through slowing or lexical access deficits. This is confirmed by the smaller number of patients (50%) impaired on the inhibition score, as that score takes into account reading/naming performance. An examination of the individual profiles on the Hayling task indicates that the results presented for the group are relatively consistent across AD patients. Over 90% of the patients were impaired on the inhibition section of the Hayling task and the size of the impairment, expressed in terms of normalized value, is large. Importantly, in 58% of these patients, the inhibition impairment was coupled with intact performance in the automatic section of the task. This supports the view that their impairment on the inhibition section of the Hayling test was not due to a semantic or lexical access deficit.

Discussion

The Hayling test was used in AD patients, normal aged persons and young participants to measure the inhibition of prepotent responses. In addition, the Stroop task, a classical test of inhibition was used as a comparison. At the group level, our findings strongly support the presence of severe inhibition deficits in groups of AD participants when considering performance on both tasks. Indeed, AD patients were slower and made more errors than elderly adults on the inhibition section of the Hayling test. As a group, persons with AD also showed marked impairment on the classical Stroop task when taking into account reading and naming speed. All but one patient were impaired on the Hayling task when looking at individual patterns of performance. In contrast, the inhibition deficit on the Stroop task was less frequent at the individual level when taking into account reading and naming.

One explanation for the AD patients' decreased performance on the Hayling test could be related to the lexical access deficit often reported in these patients (Puel, Dém-onet, Ousset, & Rascol, 1991). However, a lexical access impairment should have the opposite effect: it should slow access to the automatically activated word and, consequently, facilitate its inhibition. Furthermore, we

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found a substantial number of patients with severe inhibition impairment, yet absence of evidence for lexico-semantic deficits when considering the automatic portion of the test. Thus, it is unlikely that deficient lexical access can account entirely for the semantic inhibition deficit observed in AD patients, at least for the large portion of the group showing intact performance in the automatic portion of the task. Of course, the automatic version of this test may lack sensitivity to subtle lexico-semantic impairment and we should thus remain prudent in interpreting this part of the Hayling test.

Performance was impaired in AD patients as a group on the interference card of the Stroop test. As a group, participants with AD also showed impairment when using a score that took into account their performance on reading and color naming. The results on the Stroop task replicate the Wndings of Amieva et al. (2002) and those of Spieler et al. (1996), who also reported Stroop deficits in persons with AD. However, an examination of individual profiles indicated that in a substantial proportion of these individuals, general slowing or lexico-semantic deficits intervened in the impairment that was found on the inhibition part of the Stroop task, consistent with the data reported by Bondi and collaborators (2002). Thus, our findings qualify the impairment found at the group level, indicating that when considering reading and or naming time, the deficit remains moderate in individual persons with AD. Based on our findings and those of Bondi et al. (2002), it seems that the Stroop task impairment in AD reflects to some extent lexico-semantic deficits, in addition to an inhibition deficit. In that sense, the use of the Hayling task might be a more appropriate measure of inhibition in AD.

One additional goal of the study was to compare the effect of normal aging to that of AD by including a comparison group of young participants. The findings of the present study reveal that AD and normal aging impair similar aspects of inhibition and that the difference is primarily quantitative. Performance on the inhibition portion of the Hayling test suggests that there is a mild impairment in normal aging and a severe impairment in AD. Similarly, performance on the Stroop interference card and inhibition scores were impaired by normal aging, in addition to slower naming and reading times relative to younger participants. This is consistent with the findings of Spieler and collaborators (1996). Specifically, these authors reported that the inhibition breakdown found in persons with AD in an experimental version of the Stroop task was an amplified version of the impairment found in normal healthy persons. Our final goal was to measure whether there is a variability across AD patients on these tasks. The results were mixed on the Stroop task. Although the majority of patients were impaired on the inhibition card, the deficit might have different sources across patients. In some patients, it could arise partly form general slowing or lexical access deficits. In others, it may reflect a genuine inhibition impairment. However, our results on the inhibition portion of the Hayling task are more convincing, as the individual profiles were entirely consistent with the group characteristic. Examination of individual profiles revealed that the impairment was sufficient to reach clinical criteria (larger than 1.5 *SD* relative to matched controls) in over 90% of the AD participants, and that in many of them the impairment was independent of a lexical access deficit and extremely severe. This suggests either that the inhibition deficit found with the Hayling test is relatively impervious to patient heterogeneity, or that it occurs early in the course of the disease. Given that

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the impairment on the Hayling task is found in most patients, and given its severity, the methods used in the present study could have clinical applications for both diagnosis of the disease and the monitoring of treatment efficacy. This is important because normalized versions of the Hayling task are now being made available for use by clinicians. The results of our study suggest that the Hayling task has strong potential for characterizing and contributing to the diagnosis of AD.

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