Journal of the International Neuropsychological Society (2006), **12**, 416–423.

DOI: 10.1017/S1355617706060504

Spatial negative priming in early Alzheimer's disease: Evidence for reduced cognitive inhibition

FRANCES L. VAUGHAN,[1,3] ELIZABETH A. HUGHES,[2] ROBERT S.P. JONES,[1]
ROBERT T. WOODS,[1] AND STEVEN P. TIPPER[1]

[1]School of Psychology, University of Wales Bangor, Bangor, United Kingdom
[2]Psychology Department, South Essex Partnership NHS Trust, Essex, United Kingdom
[3]North Wales Brain Injury Service, Conwy & Denbighshire NHS Trust, United Kingdom

(RECEIVED August 13, 2005; FINAL REVISION January 30, 2006; ACCEPTED January 31, 2006)

Abstract

Some studies of negative priming and other tasks assumed to reflect inhibitory functions suggest a decline in inhibitory processes in Alzheimer's disease. However, none of the measures used in previous studies can be interpreted as an unambiguous reflection of distractor inhibition. The present study investigates whether reductions in negative priming associated with Alzheimer's disease reflect reduced distractor inhibition, rather than perceptual review processes. Individuals with early Alzheimer's disease were predicted to show reduced negative priming on a spatial localization task designed to provide an unambiguous measure of distractor inhibition. Sixteen clinical participants showed significantly less negative priming than old and young healthy control groups, which is interpreted as evidence for reduced distractor inhibition in early dementia. A second analysis indicated that, within the clinical sample only, negative priming effect size was significantly correlated with prime trial response speed. Clinical participants showing the least negative priming were slower to respond to an initial stimulus. The results may mean that people with early Alzheimer's disease have a reduced capacity to use excitatory as well as inhibitory processes in selection. (*JINS*, 2006, *12*, 416–423.)

Keywords: Alzheimer disease, Dementia, Inhibition, Attention, Cognitive science, Neuropsychology

INTRODUCTION

Recent studies and literature reviews indicate that attentional impairments develop earlier in Alzheimer's disease (AD) than was previously recognized, after the onset of memory difficulties but before aphasic, apraxic, agnosic, and visuospatial deficits are detectable (Parasuraman & Haxby, 1993; Perry & Hodges, 1999, 2000). Furthermore, progressive changes in attentional capacity correlate with other cognitive impairments and functional decline (Rizzo et al., 2000). These findings have implications for the neuropsychological assessment of early AD and our understanding of the cognitive processes that are compromised.

Some forms of attention are affected more than others in early AD. Parasuraman and Haxby (1993) reported that selective attention, divided attention, and the movement of spatial attention are all altered at an early stage. Perry and Hodges (1999) reached a similar conclusion, and later reported evidence that impairments of selective attention and the shifting of attention develop before impairments of sustained and divided attention (Perry et al., 2000). Perry and Hodges (2000) conclude that selective attention and semantic memory tests are the most likely to detect cognitive changes (other than episodic memory problems) during the earliest stages. Studies of executive function in early AD also indicate selective attention difficulties. For example, Collette et al. (1999) obtained widespread evidence of executive dysfunction and found "inhibition abilities" to be particularly affected.

It is widely assumed that the capacity to attend to one salient feature while ignoring others is facilitated by active inhibitory mechanisms that suppress irrelevant information (Houghton & Tipper, 1994). Opponent processes of activation and inhibition are thought to operate throughout the central nervous system (e.g., Rafal & Henik, 1994) and to play a fundamental role in the control of cognitive process-

Correspondence and reprints requests to: Dr. Frances Vaughan, School of Psychology, University of Wales Bangor, Brigantia Building, Penrallt Road, Bangor, Gwynedd LL57 2AS, UK. E-mail: f.vaughan@bangor.ac.uk

ing (Dagenbach & Carr, 1994). It may be then that the capacity to inhibit irrelevant information in order to attend selectively deteriorates in AD from an early stage.

Much of the evidence for selective attention impairments in AD has been obtained using neuropsychological measures, such as Stroop interference and Trailmaking errors (e.g., Grady et al., 1988; Haxby et al., 1990). Unfortunately, such data do not reflect inhibitory mechanisms directly and unambiguously (Mead et al., 2002). As Parasuraman and Haxby (1993) and Perry and Hodges (1999) have pointed out, performance on this type of selective attention task will reflect, but not distinguish between, a range of component operations, including distractor inhibition.

More recent research has attempted to identify the component operations involved in these tasks and to determine whether the selective attention impairments associated with AD represent an inhibitory impairment. Spieler et al. (1996) demonstrated that AD Stroop data, subjected to the process dissociation technique devised by Lindsay and Jacoby (1994), were consistent with the inhibitory hypothesis. Similarly, Amieva et al. (1998) analyzed Trailmaking errors and attributed most of the AD group's errors to an inhibitory deficit. Fewer healthy participant errors were related to inhibition. The results of other AD studies, in which the suppression of ambiguous word meanings (Faust et al., 1997), word reading, and rhyme decision measures (Balota & Ferraro, 1993) were interpreted as inhibition indices, were also consistent with impaired inhibition. The results of the Faust et al. study suggested that facilitatory processes remained intact.

The negative priming (NP) paradigm may shed further light on inhibitory changes in early AD. NP tasks present recently ignored distractor stimuli as targets; the slower responses made to targets that were recently ignored are attributed to inhibitory processes. It is assumed that target stimulus selection occurs partly by means of the inhibition of the internal distractor representations that compete for the control of action. If distractor representations are inhibited, then the processing of a subsequent stimulus requiring the recently inhibited representations will be impaired.

In the following NP example from Tipper (1985), the participant's task is to identify red drawings while ignoring simultaneously presented green distractor drawings. In a prime display, the red to-be-named drawing could be a "dog," while the green to-be-ignored distractor might be a drawing of a table. In the subsequent probe display, the same "table" drawing would appear in red and another object would be depicted in green. If inhibitory mechanisms act on the internal representations of the green to-be-ignored "table," the subsequent probe trial processing of this object, which requires access to the inhibited representations, will be impaired. In this example, the probe trial responses to a target picture of a table will be slower than in a control condition where the target was not recently ignored.

NP effects are frequently interpreted as a measure of distractor inhibition, couched within the selective attention model proposed by Houghton and Tipper (Houghton & Tipper, 1994; Houghton et al., 1996). This model seeks to explain the capacity to select and process relevant aspects of the environment while ignoring currently irrelevant features. Inhibitory processes suppress the representations of objects not selected for further processing, whereas excitatory processes activate relevant representations. Without inhibition, irrelevant representations would compete for further processing and slow the processing of relevant objects. Houghton and Tipper (1994) argue that the simultaneous use of excitation and inhibition produces fast and efficient object selection.

Most NP tasks involve the presentation of pictures, words, or letters for the participant to name, often with color used as the marker for target selection. For example, several studies obtained NP effects using a modified Stroop task (Dalrymple-Alford & Budayr, 1966; Lowe, 1979, 1985; Neill, 1977). More recently, tasks requiring a spatial response have been developed. In the "O-X" spatial localization task described by Tipper et al. (1990), participants pressed a key to indicate the spatial location of an O-shaped target, while ignoring an X-shaped distractor. Longer response times were measured when the O target was presented in the location occupied by the X distractor on the preceding trial.

Tipper et al. (1994) proposed that the inhibitory selection mechanisms in spatial and identity forms of NP are equivalent, in that both are determined by the behavioral goals of the task. Essentially, only the properties of the distractor that compete for control of the action are inhibited. In a naming task, only the identity of the distractor would be inhibited, whereas in a spatial task, only the representation of the distractor's location would be inhibited. Consequently, different distractor feature representations are inhibited in different tasks, and this inhibition is directly related to behavioral goals.

There have been few studies examining inhibitory processes in AD by means of NP procedures, and these studies have produced inconsistent results. Sullivan et al. (1995) used picture and word naming tasks to compare NP in older adults and people with AD. The AD group showed no evidence of NP. Similarly, Amieva et al. (2002) found no evidence of NP in an AD group using a picture naming task. In contrast, Langley et al. (1998) concluded that young adults, healthy older adults, and people with AD were equivalent on measures of NP on a letter naming task.

Although people with AD may have an inhibitory deficit that causes reduced NP, it may not be possible to use this type of identity-based NP task to identify these deficits because identity NP effects are not consistently observed in healthy older adults. Several studies (Connelly & Hasher, 1993; Hasher et al., 1991; McDowd & Oseas-Kreger, 1991; Stoltzfus et al., 1993; Tipper, 1991) have reported reduced identity NP in normal aged populations. Hence, reductions in identity NP cannot be an unequivocal marker for AD.

A solution to this difficulty may be found in spatial NP tasks, such as the O-X task described above, in which participants indicate the spatial location of the target. Younger and older adults produce identical levels of NP in these

tasks (e.g., Connelly & Hasher, 1993), and young children show adult levels (Tipper & McLaren, 1990). As age-related declines are not observed, spatial NP could provide a robust marker for changes associated with AD.

Indeed, declines in this NP measure are quite striking. Using one such technique, Simone and Baylis (1997) have shown that individuals with AD produced significantly less NP than healthy older adults, who in turn produced levels similar to healthy young adults (see Verhaeghen & De Meersman, 1998, for a meta-analysis study).

There is, however, a more important reason why previous measures of NP in individuals with AD may not accurately reflect levels of inhibitory control. An alternative to the inhibition account of NP is based on the perceptual review processes described by Kahneman et al. (1992). They suggest that an automatic review of very recent perceptual events is a part of perceptual processing that is critical for the integration of successive perceptual events. This process accesses features of objects that are no longer in view and links current and past information together to produce a coherent picture of the world. Park and Kanwisher (1994) suggested that this process could account for spatial NP effects if the perceptual differences between the prime distractor and the probe target (which occur at the same location on NP trials) were recognized. The detection of discrepancies could evoke time consuming checking processes, lead to an increase in response time on NP trials, and produce a NP effect that is unrelated to inhibition.

For example, in the traditional identification tasks (e.g., Tipper, 1985), there is an inevitable perceptual mismatch between the ignored distractor in the prime display (e.g., a green table) and the target in the subsequent probe display (e.g., a red table). Park and Kanwisher (1994) argue that this color mismatch could slow down processing of the probe; hence, the observed longer reaction times may not reflect inhibitory processes. This confound also exists in the spatial localization tasks. For example, in the Tipper et al. (1990) task, the distractor identity "X" mismatches with the probe target's identity of "O"; or in the Simone and Baylis (1997) task, the distractor was green and the subsequent target was red.

Consequently, previously reported NP effects obtained using traditional tasks may be ambiguous. NP effects cannot be assumed to reflect distractor inhibition alone, and the reduction of NP levels reported for some clinical groups (e.g., people with schizophrenia; Beech et al., 1989; Laplante et al., 1992) might instead reflect a reduced capacity to review recent perceptual events.

The spatial localization task used in the present study was designed to remove this confound. That is, it was developed specifically to elicit NP effects that can be assumed to reflect distractor inhibition rather than perceptual review processes (see, Milliken et al., 1994; Tipper et al., 1995). The critical aspect of the task is that the prime distractor and the subsequent probe target are perceptually identical, so that no distractor–target mismatch can be perceived.

In summary, there are several reasons for undertaking this study. First, almost all previous studies examining declines in inhibition in AD by means of NP techniques have used a target identification task. Unfortunately, healthy older adults also show declines in NP in this task, so it may not be an unequivocal marker for AD. Second, all previous studies contain the perceptual mismatch confound. Reduced NP in people with AD may reflect impairments in detecting such mismatches, whereas inhibition may be normal. The procedure to be described here avoids these confounds and provides a more unequivocal measure of inhibitory processing in AD. Furthermore, the task is simple and relatively short to administer and, therefore, may be of potential use in detecting early onset AD in the clinic. The hypothesis addressed here is that people with early AD use less inhibition in target selection. It is predicted that participants with AD will show reduced NP in a task for which perceptual differences between the prime distractor and probe target are eliminated.

METHOD

Ethical approval for this study was obtained from the Research Ethics Committees of the School of Psychology, University of Wales, Bangor, and the North West Wales NHS Trust.

Participants

There were 16 individuals (5 women, 11 men) who fulfilled the NINCDS-ADRDA criteria for probable AD (McKhann et al., 1984), 16 healthy older adults (12 women, 4 men), and 16 young healthy adults (11 women, 5 men) participated.

The AD group had been assessed for possible dementia by a psychiatrist and clinical psychologist from a North West Wales NHS Trust multidisciplinary older adults team. Half of the AD group was seen at home, half in the Day Hospital. All participants lived independently.

The older adult control group (OA) was selected to match the clinical sample on age and estimated premorbid ability. These participants were recruited either through the University of Wales Bangor School of Psychology participant panel or with the help of a local medical practice. The latter were contacted by their family doctor and responded if they wished to take part. Most OA participants were seen at home; a small number were seen at the university or in the medical practice. The young adult control participants (YA) were recruited by means of the School of Psychology student participant panel and assessed at the university.

Mean (and *SD*) age in years was 76.9 (5.7), 76.4 (4.9), and 20.6 (2.9) for the AD, OA, and YA groups, respectively. Mean (and *SD*) estimated premorbid Full-Scale IQ values were 107.5 (11.8), 113.1 (10), and 114.3 (4.6), respectively (Nelson & Willison, 1991). The older groups did not differ significantly in age ($F(1,30) = .03$). Estimated premorbid ability did not vary significantly across the three groups ($F(2,45) = 2.4$, not significant [ns]).

https://doi.org/10.1017/S1355617706060504 Published online by Cambridge University Press

All participants were able to see, hear, and use their dominant hand well enough to comply with the task instructions and were able to complete the task making fewer than 5% errors. Individuals were excluded if they had a mental illness, a psychiatric or neurological history, or were taking prescribed psychoactive medication other than sleeping tablets.

Dementia severity was characterized using the Clinical Dementia Rating (CDR) scale (Hughes et al., 1982). Ratings are based on the clinical assessment of memory, orientation, judgment, community affairs, home and hobbies, and personal care. An overall CDR score of 1 indicates mild dementia, whereas a score of 0.5 indicates very mild dementia. Half of the AD sample obtained an overall CDR score of 1; half obtained an overall score of 0.5. All OA participants obtained a CDR of 0.

Apparatus

The NP data were collected using an IBM-compatible 486/33 portable microcomputer attached to an SVGA color monitor. Responses were made with a Kraft KC30 joystick linked through the game port. Response times (RTs) were computed to the nearest millisecond (ms).

Design

The task was to select the larger of two circles (see Figure 1). On the prime trial, a smaller distractor circle (size 2) always accompanied the larger target circle (size 3). On the probe trial, the previous distractor (size 2) was always presented with a smaller circle (size 1) and so was selected as the target. The probe trials were divided between control and ignored repetition trials. On control trials, the probe target was physically identical to the prime distractor but appeared in a different location. The two circles appeared in the two locations that had not been occupied on the prime trial. On ignored repetition trials, the target (a size 2 circle) appeared in the location previously occupied by the identical prime trial distractor. In an attempt to conceal the NP manipulation, only one third of the probe trials were ignored repetition trials.

Procedure

All participants provided written consent. Participants completed the NP task followed by the Cambridge Contextual Reading Task (Beardsall & Huppert, 1994), which provided an estimate of premorbid ability. The NP task was a modified form of the procedure described by Watson and Tipper (1997). In the modified form, the stimuli remained on the screen until the participant made a response, and initial practice was unrestricted. The task was demonstrated, and the investigator provided verbal instructions. These instructions indicated that two circles would be presented simultaneously and that one circle would be larger than the other. Participants were asked to indicate the location of the larger circle as quickly as possible by making a spatially compatible joystick movement (up, down, left, or right). Participants practiced the task until they could make fluent motor responses. The AD participants did not require significantly more practice than the controls. The task comprised 90 prime-probe pairs of trials with a compulsory 30-second rest halfway through. Data collection lasted approximately 10 minutes.

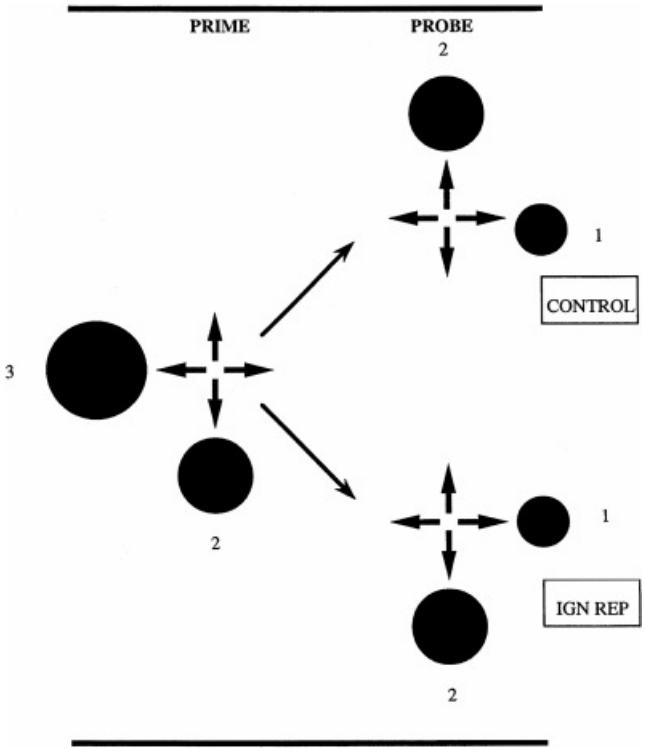

Fig. 1. Examples of negative priming task stimuli for control and ignored repetition trials. Note that the numbers denote the circle sizes and were not included in the stimulus display. IGN REP = ignored repetition.

The stimuli were solid dark gray circles of three different sizes (1, 2, and 3). At a viewing distance of 70 cm, the diameters of the circles (in degrees of visual angle) were 0.49 degrees for size 1, 0.74 degrees for size 2, and 0.98 degrees for size 3. The circles appeared on a light gray background in two of four possible locations, with four dark gray arrows (pointing up, down, left, and right from the center of the screen) used to mark the four possible locations. The distance from the tip of the left pointing arrow to the tip of the right pointing arrow and from the tip of the upward pointing arrow to the tip of the downward pointing arrow was 3.03 degrees. Each circle was centered on a point 1.06 degrees from the tip of its arrow marker.

The investigator initiated each trial pair sequence. The four arrow markers appeared on the screen and remained visible throughout each trial. The first trial display was presented 1500 ms after the arrows appeared. One circle was displayed at the tip of each of two arrows. The prime trial

https://doi.org/10.1017/S1355617706060504 Published online by Cambridge University Press

display remained on the screen until a response was made. After the response, the display vanished, leaving only the arrows on the screen for 357 ms. The probe trial display was presented and remained on the screen until the response. The screen was cleared, and the prompt to initiate the next trial appeared.

An accurate response and the associated response time were recorded if the joystick was moved to within 45 degrees to either side of the correct position. An error was recorded if the joystick was moved in any of the three nontarget directions or if the joystick did not immediately spring back to its central position after the response.

RESULTS

Analysis 1: The Effect of Early Alzheimer's Disease on Distractor Inhibition

The RT data comprised three individual median RT values: the prime trial median RT, the control probe trial median RT, and the ignored repetition probe trial median RT (Table 1). A raw RT value was included in the median calculation only if correct responses had been made on both the prime trial and the probe trial of the pair of trials in question.

Prime trial RTs were examined in a one-way analysis of variance (ANOVA), which revealed significant group differences ($F(2,45) = 13.9$; $p < .001$). Bonferroni post hoc comparisons indicated that the YA group made significantly faster responses than the older groups (both $p < .001$).

A two-way mixed ANOVA examined median control probe trial RTs and median ignored repetition probe trial RTs. The NP manipulation was represented by a within-subject repeated measures factor, referred to as Trial Type (Control Trial *vs.* Ignored Repetition Trial). The between-subject factor was Group (AD *vs.* OA *vs.* YA). There was a significant Group effect ($F(2,45) = 10.9$; $p < .001$) but no Trial Type effect ($F(1,45) = 1.05$, ns). However, the critical Group × Trial Type interaction was significant ($F(2,45) = 5.7$; $p < .01$), indicating group differences in NP.

Bonferroni post hoc comparisons indicated that the YA group differed from both older groups (AD *vs.* YA $p < .01$, OA *vs.* YA $p < .001$). Young participants made faster responses than the older groups. The Group × Trial Type interaction was examined using paired t tests to compare control and ignored repetition probe RTs within each group. There was no significant priming effect in the AD data ($t = 1.46$, ns). However, replicating previous studies (e.g., Tipper et al., 1995; Watson & Tipper, 1997), there were significant NP effects for the controls (OA $t = -3.5$, $p < .005$; YA $t = -2.4$, $p < .05$). Although the overall AD priming effect was nonsignificant, a large proportion (11/16) of the group showed individual positive priming effects. In contrast, 12 OA participants showed individual NP effects ($\chi^2 = 6.2$; $p < .03$).

The interaction was examined further by comparing the groups in terms of the magnitude of the priming effects they obtained. A one-way ANOVA of the RT difference scores representing priming effects (mean control probe trial RT minus mean ignored repetition probe RT) indicated significant group differences ($F(2,45) = 5.7$; $p < .01$). Further analysis indicated that the AD group differed significantly from the OA group ($t = 2.8$; $p = .01$) and the YA group ($t = 2.3$; $p < .05$). The OA and YA groups did not differ ($t = -.9$, ns). To control for age-related slowing (e.g., Faust et al., 1999), the same analyses were performed on proportion transformed priming effects. The difference scores described above were divided by the mean control probe trial RT. The ANOVA indicated significant differences ($F(2,45) = 4.4$; $p = .02$), and the t test results mirrored those above (AD *vs.* OA $t = 2.5$; $p = .02$; AD *vs.* YA $t = 2.2$; $p = .04$; OA *vs.* YA $t = -.3$, ns). Given the small effect sizes obtained in NP studies, it was recognized that the statistical power may not have been sufficient to detect real underlying differences. However, a power calculation for the comparison of the AD and OA NP effects revealed power to be .86 (at .05).

Errors were analyzed in the same way as the RT data, but there were no significant effects. The effect of gender on RT data was also examined, as the AD and the control groups had unbalanced opposing distributions. The t tests (within

Table 1. Group mean of median response times (RTs; ms) and RT priming effects (ms)

	Prime trial		Probe control		Trial type Ignored repetition		Priming effect (raw and proportional)	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Clinical	671	98	716	137	696	111	+20.00 +.02	55.00 .08
Older adults	660	94	703	160	726	156	−23.00 −.04	26.00 .04
Young adults	521	84	525	84	540	84	−15.00 −.03	24.00 .05

https://doi.org/10.1017/S1355617706060504 Published online by Cambridge University Press

and between groups) indicated that gender had no significant effect on NP.

Analysis 2: Does Distractor Inhibition Mean More Efficient Selection?

A further objective was to examine the impact of reduced distractor inhibition on the efficiency of target selection. If the size of an NP effect reflects the degree to which distractor inhibition is used during selection, such that target selection efficiency improves with increased inhibition, then larger individual NP effects may be associated with faster prime selection responses.

Here, the correlation between individual NP effect size and prime trial RT measures were examined within each of the three participant groups described above. Only the AD group correlation was significant ($r = .61$; $p = .01$). For the clinical group, faster prime trial response times were associated with larger NP effects. This finding suggests that individuals with AD who had retained the capacity to inhibit distractor representations were also able to select targets more efficiently.

DISCUSSION

Increasing evidence of attentional impairments in early AD has been reported over the past 10 years. Selective attention deficits have been a predominant feature, consistent with the possibility that early AD involves difficulty with the inhibition of irrelevant information. Unfortunately, previous techniques used to measure inhibition by means of NP have contained possible confounds (e.g., identity inhibition may decline in normal ageing; identity-based NP tasks produce perceptual mismatches). Therefore, new techniques were required to test the hypothesis that declines in inhibition are a feature of early AD. The results obtained provide direct evidence in support of this hypothesis.

The NP effects obtained by the OA and YA control groups were statistically significant and of a similar proportional magnitude. This finding is consistent with previously reported evidence that spatial NP effects are retained in old age, whereas identity-based NP effects may decline. The present results indicate that people with early AD do not show significant spatial NP. This finding is consistent with results reported by Simone and Baylis (1997), who found equivalent spatial NP in young and older adults on a selective reaching task but no NP in patients with AD. Furthermore, due to the elimination of perceptual discrepancies between the prime distractor and probe target in this study, our results can be more clearly interpreted as evidence for reduced distractor inhibition in early AD. Given that the present results were obtained using a spatial localization task rather than a higher-level semantic or naming task, they also suggest that early AD affects the use of inhibition at relatively low processing levels.

Before considering theoretical accounts that describe inhibitory selection mechanisms, it is worthwhile considering an alternative account at this point. Neill et al. (1992) proposed that NP might not result from inhibition of distractors but rather from retrieval from the prime display of mismatching information. For example, it was proposed that the prime distractor is encoded as "do not respond to me". When this same stimulus is encountered in the probe display, it is labeled "respond to me," as it is now a target. During processing of the probe, the prior processing episode of the prime is retrieved, and the "do not respond to me" label is activated: this information conflicts with the current encoding of the target ("respond to me"), resulting in slower response times. Although Tipper (2001) acknowledged that the notion of retrieval of prior processing episodes was extremely important, as such retrieval was probably taking place in priming procedures, it was noted that the mediating neural processes of such verbal labels as "do not respond to me" would probably be inhibition processes.

Furthermore, we are not convinced that retrieval of response tags can explain the reduced NP in our clinical group. In the Neill et al. (1992) account, the absence of an NP effect would be attributed to a failure to retrieve the prime distractor's "do not respond to me" tag when the stimulus was presented as the probe target. Failure to retrieve the tag would not result in priming of any sort.

The AD and OA groups varied in terms of the direction of the priming effects they showed. Whereas most OA participants exhibited negative priming, 73% of the clinical group made faster responses to previously ignored stimuli than they did to neutral stimuli. These modest but prevalent AD facilitation effects may reflect something other than the absence of a NP effect caused by a failure to retrieve a tag. We suggest instead that they reflect the absence of distractor inhibition, and the facilitatory effect of the distractor activation on subsequent selection. In the inhibition model, distractors can be associated with either inhibition or excitation and an inhibition failure would predict the faster processing of previously ignored (but not inhibited) distractors. Therefore, the effects obtained are more compatible with the inhibition model than with the retrieval account.

Furthermore, there was a correlation between efficiency in selecting the target in the prime display and the pattern of priming. This correlation would not be expected from occasional failures to retrieve "do not respond" tags, but as noted below, it would be a natural consequence of an account in which NP reflects an inhibition mechanism acting on distractors with different levels of efficiency.

Therefore, our preferred theoretical framework for interpreting these data is the computational model developed by Houghton and Tipper (1994). An important feature of this model is that selection of a target is achieved by means of two parallel mechanisms. The first is excitation, which feeds back to the internal representations of the target, boosting activation states. Simultaneously, a second mechanism of inhibition feeds back to the distractor's representations and suppresses these. By means of this dual mechanism, very

https://doi.org/10.1017/S1355617706060504 Published online by Cambridge University Press

efficient selection is achieved. Importantly, Houghton and Tipper (1994) suggested that these mechanisms could be independent, being mediated by separate neurotransmitter systems. Thus, a decline in the efficiency of one mechanism need not be observed in the other mechanism. Indeed, a decline in one mechanism could be compensated for by increased efficiency of the other selection mechanism. Therefore, it is not surprising that a decline in NP does not always result in less-efficient target selection (see Houghton et al., 1996; Tipper, 2001, for further discussion) and that, consistent with these previous observations, the control groups showed no correlation between NP and prime trial RT in the present study. For the controls, selection efficiency would depend upon intact and mutually compensating facilitatory and inhibitory processes. Transient reductions in inhibition would be counteracted by increased excitation (and vice versa), and reductions in NP would be unrelated to response speed.

However, a different pattern was observed in the AD group. Here, less-efficient selection of the prime target (reflected by means of slower prime reaction times) was associated with declines in levels of inhibition, as measured by means of NP. This association is an intriguing observation. It is proposed that both inhibitory and excitatory systems may be failing in early AD. There may be not only a decline in inhibition, but also a decline in the ability to use excitation to compensate for reduced inhibition. Under these conditions, NP effects would be correlated with selection efficiency (prime RT). If both systems fail to some degree, then individuals with less inhibitory capacity will be less efficient. Note, however, that there was no significant difference between the AD and OA groups on prime trial response speed. This finding is important given that the prime display remained visible until the response. It indicates that the less-efficient prime target selection observed in some AD participants was not caused by the participants responding so slowly that they shifted their attention overtly and processed the distractor actively.

The NP task used here is short and easy to implement. However, although we obtained significant group differences in NP, a small number of individuals with AD did show NP effects, and so the task is not sensitive enough to be used as a diagnostic test. Nevertheless, NP evidence may be useful in identifying individuals with inhibitory and selection impairments, who might benefit from attentional training (e.g., Graf et al., 1990) and the environmental reduction of extraneous distraction (Woods, 1996).

ACKNOWLEDGMENTS

This research was conducted as part of the first and second authors' training in Clinical Psychology, funded by the Welsh Office, United Kingdom. We are grateful to Dr. Antony Vaughan and the staff of Bron Derw Medical Center, Bangor, for help with the recruitment of the older adult control participants; to Linda Evans for help with the CDR scoring; and to Sheryl Davison for conducting the young adult experiment.

REFERENCES

Amieva, H., Lafont, S., Auriacombe, S., Le Carret, N., Dartigues, J-F., Orgogozo, J-L., & Fabrigoule, C. (2002). Inhibitory breakdown and dementia of the Alzheimer type: A general phenomenon? *Journal of Clinical and Experimental Neuropsychology*, *24*, 503–516.

Amieva, H., Lafont, S., Auriacombe, S., Rainville, C., Orgogozo, J.M., Dartigues, J.F., & Fabrigoule, C. (1998). Analysis of error types in the Trailmaking test evidences an inhibitory deficit in dementia of the Alzheimer type. *Journal of Clinical, & Experimental Neuropsychology*, *20*, 280–285.

Balota, D.A. & Ferraro, F.R. (1993). A dissociation of frequency and regularity effects in pronunciation performance across young and healthy adults, older adults and individuals with senile dementia of the Alzheimer's type. *Journal of Memory and Language*, *32*, 573–592.

Beardsall, L. & Huppert, F.A. (1994). Improvement in NART word reading in demented and normal older persons using the Cambridge Contextual Reading Test. *Journal of Clinical and Experimental Neuropsychology*, *16*, 232–242.

Beech, A., Powell, T., McWilliam, J., & Claridge, G. (1989). Evidence of reduced 'cognitive inhibition' in schizophrenia. *British Journal of Psychology*, *28*, 109–116.

Collette, F., Van der Linden, M., & Salmon, E. (1999). Executive dysfunction in Alzheimer's disease. *Cortex*, *35*, 57–72.

Connelly, S.L. & Hasher, L. (1993). Aging and the inhibition of spatial location. *Journal of Experimental Psychology: Human Perception and Performance*, *19*, 1238–1250.

Dagenbach, D. & Carr, T. (1994). Inhibitory processes in perceptual recognition: Evidence for a center-surround attentional mechanism. In D. Dagenbach & T. Carr (Eds.), *Inhibitory processes in attention, memory and language*. San Diego: Academic Press.

Dalrymple-Alford, E.C. & Budayr, B. (1966). Examination of some aspects of the Stroop color-word test. *Perceptual and Motor Skills*, *23*, 1211–1214.

Faust, M.E., Balota, D.A., Duchek, J.M., Gernsbacher, M.A., & Smith, S. (1997). Inhibitory control in sentence comprehension in individuals with dementia of the Alzheimer type. *Brain and Language*, *57*, 225–253.

Faust, M.E., Balota, D.A., Spieler, D.H., & Ferraro, F.R. (1999). Individual differences in information processing rate and amount: Implications for group differences in response latency. *Psychological Bulletin*, *125*, 777–799.

Grady, C.L., Haxby, J.V., Horwitz, B., Sundaram, M., Berg, G., Schapiro, M., Friedland, R.P., & Rappoport, S.I. (1988). Longitudinal study of the early neuropsychological and cerebral metabolic changes in dementia of the Alzheimer's type. *Journal of Clinical and Experimental Neuropsychology*, *10*, 576–596.

Graf, P., Tuokko, H., & Gallie, K. (1990). Attentional deficits in Alzheimer's disease and related dementias. In J.T. Enns (Ed.), *The development of attention: Research and theory*. Elsevier: North Holland.

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

Haxby, J.V., Grady, C.L., Koss, E., Horowitz, B., Heston, L.L., Schapiro, M.B., Friedland, R.P., & Rappoport, S.I. (1990). Longitudinal study of cerebral metabolic asymmetries and associated neuropsychological patterns in early dementia of the Alzheimer type. *Archives of Neurology*, *47*, 753–760.

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

Houghton, G., Tipper, S.P., Weaver, B., & Shore, D.I. (1996). Inhibition and interference in selective attention: Some tests of a neural network model. *Visual Cognition*, *3*, 119–164.

Hughes, C.P., Berg, L., Danziger, W.L., Coben, L., & Martin, R. (1982). A new clinical scale for the staging of dementia. *British Journal of Psychiatry*, *140*, 566–572.

Kahneman, D., Treisman, A., & Gibbs, B.J. (1992). The reviewing of object files: Object-specific integration of information. *Cognitive Psychology*, *24*, 175–219.

Langley, L.K., Overmier, J.B., Knopman, D.S., & Prod'Homme, M.M. (1998). Inhibition and habituation: Preserved mechanisms of attentional selection in aging and Alzheimer's disease. *Neuropsychology*, *12*, 353–66.

Laplante, L., Everett, J., & Thomas, J. (1992). Inhibition through negative priming with Stroop stimuli in schizophrenia. *British Journal of Clinical Psychology*, *31*, 307–326.

Lindsay, D.S. & Jacoby, L. (1994). Stroop process dissociations: The relationship between facilitation and interference. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 219–234.

Lowe, D.G. (1979). Strategies, content and the mechanisms of response inhibition. *Memory and Cognition*, *7*, 382–389.

Lowe, D.G. (1985). Further investigations of inhibitory mechanisms in attention. *Memory and Cognition*, *13*, 74–80.

McDowd, J.M. & Oseas-Kreger, D.M. (1991). Aging, inhibitory processes, and negative priming. *Journal of Gerontology*, *46*, 340–345.

McKhann, G., Drachman, D., Folstein, M., Katzman, R., Price, D., & Stadlan, E.M. (1984). Clinical diagnosis of Alzheimer's disease: Report of the NINCDS-ADRDA work group under the auspices of the Department of Health and Human Services task force on Alzheimer's disease. *Neurology*, *34*, 939–944.

Mead, L.A., Mayer, A.R., Bobholz, J.A., Woodley, S.J., Cunningham, J.M., Hammeke, T.A., & Rao, S.M. (2002). Neural basis of the Stroop interference task: Response competition or selective attention? *Journal of the International Neuropsychological Society*, *8*, 735–742.

Milliken, B., Tipper, S.P., & Weaver, B. (1994). Negative priming in a spatial localization task: Feature mismatching and distractor inhibition. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 624–646.

Neill, W.T. (1977). Inhibition and facilitation processes in selective attention. *Journal of Experimental Psychology: Human Perception and Performance*, *3*, 444–450.

Neill, W.T., Valdes, L.A., Terry, K.M., & Gorfein, D.S. (1992). Persistence of negative priming: II. Evidence for episodic trace retrieval. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *18*, 993–1000.

Nelson, H.E. & Willison, J.R. (1991). *The National Adult Reading Test manual* (2nd ed.). Windsor, Berks: NFER-Nelson.

Parasuraman, R. & Haxby, J.V. (1993). Attention and brain function in Alzheimer's Disease. *Neuropsychology*, *7*, 242–272.

Park, J. & Kanwisher, N. (1994). Negative priming for spatial locations: Identity mismatching not distractor inhibition. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 613–623.

Perry, R.J. & Hodges, J.R. (1999). Attention and executive deficits in Alzheimer's disease: A critical review. *Brain*, *122*, 383–404.

Perry, R.J. & Hodges, J.R. (2000). Fate of patients with questionable (very mild) Alzheimer's disease: Longitudinal profiles of individual subjects' decline. *Dementia and Geriatric Cognitive Disorders*, *11*, 342–349.

Perry, R.J., Watson, P., & Hodges, J.R. (2000). The nature and staging of attention dysfunction in early (minimal and mild) Alzheimer's disease: Relationship to episodic and semantic memory impairment. *Neuropsychologia*, *38*, 252–271.

Rafal, R. & Henik, A. (1994). The neurology of inhibition. In D. Dagenbach & T. Carr (Eds.), *Inhibitory processes in attention, memory and language*. San Diego: Academic Press.

Rizzo, M., Anderson, S.W., Dawson, J., Myers, R., & Ball, K. (2000). Visual attention impairments in Alzheimer's disease. *Neurology*, *54*, 1954–1959.

Simone, P.M. & Baylis, G.C. (1997). Selective attention in a reaching task: Effect of normal aging and Alzheimer's disease. *Journal of Experimental Psychology: Human Perception, & Performance*, *23*, 595–608.

Spieler, D.H., Balota, D.A., & Faust, M.E. (1996). Stroop performance in healthy younger and older adults and in individuals with dementia of the Alzheimer's type. *Journal of Experimental Psychology: Human Perception, & Performance*, *22*, 461–479.

Stoltzfus, E.R., Hasher, L., Zacks, R.T., Ulivi, M.S., & Goldstein, D. (1993). Investigations of inhibition and interference in younger and older adults. *Journal of Gerontology*, *48*, 179–188.

Sullivan, M.P., Faust, M.E., & Balota, D.A. (1995). Identity negative priming in older adults with dementia of the Alzheimer's type. *Neuropsychology*, *9*, 537–555.

Tipper, S.P. (1985). The negative priming effect: Inhibitory priming by ignored objects. *Quarterly Journal of Experimental Psychology*, *37A*, 571–590.

Tipper, S.P. (1991). Less attentional selectivity as a result of declining inhibition in older adults. *Bulletin of the Psychonomic Society*, *29*, 45–47.

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

Tipper, S.P. & McLaren, J. (1990). Evidence for efficient visual selectivity in children. In J.T. Enns (Ed.), *Advances in psychology. The development of selective attention: Research and theory*. North Holland: Elsevier Science Publishers,.

Tipper, S.P., Brehaut, J.C., & Driver, J. (1990). Selection of moving and static objects for the control of spatially directed action. *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 492–504.

Tipper, S.P., Weaver, B., & Houghton, G. (1994). Behavioral goals determine inhibitory mechanisms of selective attention. *Quarterly Journal of Experimental Psychology*, *47A*, 809–840.

Tipper, S.P., Weaver, B., & Milliken, B. (1995). Spatial negative priming without mismatching: Comment on Park and Kanwisher (1994). *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 1220–1229.

Verhaeghen, P. & De Meersman, L. (1998). Aging and the negative priming effects: A meta-analysis. *Psychology and Aging*, *13*, 435–444.

Watson, F.L. & Tipper, S.P. (1997). Reduced negative priming in high schizotypes does reflect reduced cognitive inhibition: Evidence from a spatial localization task. *Cognitive Neuropsychiatry*, *2*, 67–79.

Woods, R.T. (1996). Cognitive approaches to the management of dementia. In R.G. Morris (Ed.), *The cognitive neuropsychology of Alzheimer-type dementia*. Oxford: Oxford University Press.