Time reproduction during high and low attentional tasks in Alzheimer's disease "A watched kettle never boils"

Mohamad EL HAJ [1], Diana OMIGIE [2, 3, 4], Christine MORONI [2]

[1] Laboratoire Epsylon, EA 4556, Université Paul-Valery, Montpellier III, France

[2] Neuropsychology and Auditory Cognition, Department of Psychology, University of Lille 3, France.

[3] Centre de Neuroimagerie de Recherche (CENIR), Paris, France

[4] Centre de Recherche de l'Institut du Cerveau et de la Moëlle Épinière (ICM), UPMC - UMR 7225 CNRS - UMRS 975 INSERM, Paris, France.

Correspondence concerning this article should be addressed to: Mohamad EL HAJ, Laboratoire Epsylon EA 4556, 4 Rue du Pr. Henri Serre, 34000 Montpellier, France. E-mail: mohamad.el-haj@univ-montp3.fr

A wealth of empirical evidence suggests that directing attention to temporal processing increases perceived duration, whereas drawing attention away from it has the opposite effect. Our work investigates this phenomenon by comparing perceived duration during a high attentional and a low attentional task in Alzheimer's Disease (AD) patients since these participants tend to show attentional deficits. In the high attentional task, AD patients and older adults were asked to perform the interference condition of the Stroop test for 15s while in the low attentional task, they had to fixate on a cross for the same length of time. In both conditions, participants were not aware they would be questioned about timing until the end of the task when they had to reproduce the duration of the previously-viewed stimulus. AD patients under-reproduced the duration of previously-exposed stimulus in the high attentional relative to the low attentional task, and the same pattern was observed in older adults. Due to their attentional deficits, AD patients might be overwhelmed by the demand of the high attentional task, leaving very few, if any, attentional resources for temporal processing.

Keywords: Alzheimer's Disease, attention, perceived duration, time perception, time reproduction

1. Introduction

“A watched kettle never boils” and “Time flies when you're having fun” are just two well-known adages that allude to the intimate relationship between attention and timing. Further evidence of this link is provided by experimental data showing that temporal intervals during low attentional tasks are perceived longer than those during high attentional tasks (for a review, see, Grondin, 2010; Phillips, 2012). With regard to the latter, it has been suggested that duration judgments decrease as task complexity increases because the greater attentional resources demanded by a task leave fewer attentional resources available for time processing (Zakay and Block, 1996).

To explain the link between attention and timing, Zakay and Block proposed a model (1996) in which a pacemaker that generates pulses and an accumulator that counts them are separated by an attentional gate. They suggested that when an organism pays attention to time the gate opens wider, allowing the passage of more pulses to the accumulator per unit time, and therefore leading to an overestimation of time. Analogously, in situations where attention is not focused on the elapsing time, the number of accumulated pulses decreases, and consequently, time duration will be underestimated. Also arguing that duration over-estimation occurs when attentional resources are focused on timing, Dutke (2005) went so far as to suggest that the target of attentional resources may be one of the most important cognitive factors influencing duration judgments.

Attention is remarkably attenuated by aging (for a review, see, Verhaeghen and Cerella, 2002) and therefore how the duration of low and high attentional tasks is perceived and estimated by older adults is a question of great interest. Several authors (Craik and Hay, 1999; Gruber et al., 2004) have suggested that a decline in attentional resources will contribute to acceleration of subjective time with aging. Specifically, it has been suggested that because older adults have diminished attentional resources, their sense of prospective time should shorten, particularly in intervals characterized by high attentional demands (Gruber et al., 2004).

Those with Alzheimer's Disease (AD) also present an interesting group to study as they often present with disorders of temporal processing whereby they tend to show significant alterations in the judgment of time (Carrasco et al., 2000; Caselli et al., 2009; El Haj et al., 2013; Nichellli et al., 1993; Papagno et al., 2004; Rueda and Schmitter-Edgecombe, 2009). In one study (Carrasco et al., 2000), AD patients were asked to produce three prospective empty intervals, lasting 5s, 10s, or 25s. Results showed that in all three conditions, they produced intervals that were not only greater than those produced by control participants but also that differed significantly from real intervals. In another study, Papagno et al. (2004) asked AD patients to prospectively estimate the duration of one low attentional and two high attentional tasks. In the low attentional task, participants had to pronounce syllables. In the high attentional tasks, they had to 1) press a key each time a ball entered a specific target square, and 2) repeat back sequences of digits. Here, as well, the AD patients overestimated time durations during all the three tasks, particularly the high attentional ones.

Critically, while results reporting overestimation of duration of low attentional tasks in AD patients like those from Carrasco et al. (2000) and Pagano et al. (2004) might be expected, those from Papagno et al. (2004), also reporting overestimation of high attentional ones may be considered unexpected. Indeed, while the overestimation of the 'empty' intervals such as used in the study of Carrasco et al. (2000) may be explained as the participants deploying their attentional processes on timing (Zakay and Block, 1996), in light of the previously described attentional theories (Dutke, 2005; Zakay and Block, 1996), high attentional tasks would be expected to be underestimated not overestimated as was found by Papagno et al. (2004).

One possibility is that these results are reconcilable by the specific nature of the temporal task employed by Block (Block et al., 2010 Grondin, 2008, 2010; Mioni et al., 2013) or by the prospective nature of the tasks used by Carrasco et al. (2000) and Papagno et al. (2004). In prospective tasks, participants, being aware of timing, deploy their attentional resources toward timing processes and consequently overestimate time. This assumption fits well with the model of Zakay and Block (1996). Following the assumption of Zakay and Block (1996), we suggest that the previous use of prospective tasks in papers dealing with time perception in AD has led to a bias of the usual observation that duration judgment decreases as task complexity increases. Our paper addresses this confound in the literature by comparing time estimation during low attentional and high attentional tasks using a retrospective approach.

Temporal discrimination tasks are held to activate the 'cortico-thalamic-basal ganglia timing circuit'- an extended network encompassing basal ganglia, and generally right lateralized prefrontal, superior temporal and inferior parietal cortices (Coull et al., 2004; Morillon et al., 2009; Rao et al., 2001). The role of the frontal cortices is believed to be the 'reading out' of firing activity of the spiny neurons comprising the cortico-thalamic-basal ganglia timing circuit (for a review see Merchant et al., 2013). Impairments to the functioning of these frontal areas, due to for instance aging or AD, may be expected therefore to also compromise performance on temporal discrimination tasks.

In summary, it is well established that directing attention to temporal processing increases perceived duration, whereas distracting attention from time decreases perceived duration (Dutke, 2005; Zakay and Block, 1996). Research in AD (Papagno et al., 2004) may have failed to support such a pattern due to its use of prospective tasks that direct attention to time. We addressed this shortcoming by assessing perceived duration of low attentional and high attentional tasks using a retrospective approach. In line with the vast body of literature on this subject (Dutke, 2005; Graf and Grondin, 2006; Phillips, 2012; Zakay and Block, 1996), and especially aging research (Craik and Hay, 1999; Gruber et al., 2004), we predicted that AD patients would underestimate the duration of tasks associated with high attentional relative to low attentional load. Specifically, given that the frontal lobes are involved in governing attentional processing and timing mechanisms (Merchant et al., 2013) and further given that these areas become impaired in aging and AD (Raz, 2000), we predicted greater time deviations in high attentional relative to low attentional tasks in both normal aging and AD.

2. Method

2.1. Participants

Seventeen subjects with probable AD and 18 healthy older adults voluntarily participated in the present study. Details of participants' demographics and neuropsychological performance are given in Table 1. AD participants, meeting NINCDS-ADRDA (National Institute of Neurological and Communicative Disorders and Stroke–Alzheimer's Disease and Related Disorders Association McKhann et al., 1984) criteria for probable AD, were recruited from local retirement homes. Healthy older adults were often the spouses, relatives or friends of the AD participants. In order to assess their cognitive ability, all the participants were assessed with a neuropsychological battery including 1) general cognitive ability: the Mini Mental State Examination, the maximum score was 30 points (Folstein et al., 1975), 2) spontaneous flexibility: participants were given 2 min to generate as many words beginning with the letter P, 3) working memory: participants repeated a series of numbers in the forward digit span task (in the reverse order for the backward digit task), and 4) episodic memory: on the 5-words test (Dubois et al. 2002), participants had to remember, on a 2 min-delayed task, five words in free recall and, if necessary, a categorical cued recall. In general, AD patients showed poorer neuropsychological performance than older adults, confirming their diagnosis.

All participants were French native speakers and reported normal or corrected-to-normal visual and auditory acuity. None of them had encountered the loss of a relative within one month before the assessment. Exclusion criteria were: traumatic brain damage, cerebrovascular disease, significant psychiatric or neurological illness, history of clinical depression and alcohol or drug use.

[INSERT TABLE 1 APPROXIMATELY HERE]

2.2. Apparatus

A laptop computer with a 15-inch LCD display was used for presenting the timing tasks. Stimuli presentation and response recording were controlled using the software package Psychopy (Peirce, 2007).

2.3. Procedures

The participants were tested individually in a time estimation task with a low attentional load and a time estimation task with a high attentional load, both of which lasted 15s. This interval was chosen for two reasons. Firstly, short intervals (< 30s) are argued to allow the examination of absolute errors in AD patients (Carrasco et al., 2000), (difference between subjective timing and real time), a variable considered in our study. Secondly, the reproduction design, as used in this paper, required reproducing the duration of previously-presented stimulus. Prone to fatigability, distractibility, and inhibitory deficits decreasing their motor control, AD participants may precipitate the end of the reproduction phase, especially for long intervals resulting in biased performance.

In the low attentional load task, designed to minimize attentional demands, participants were asked to fixate, for 15s, on a black-colored fixation cross (+), presented in the center of a gray screen. In the high attentional load task, performance on the interference condition of the Stroop task was assessed. Fifty stimuli, referring to color-words displayed in incongruously colored ink (e.g., the word ‘‘blue’’ displayed in red), were exposed at the center of a gray screen for 15s, and participants were required to name the color of the word regardless of its meaning. During both the low attentional and high attentional tasks, the participants were unaware of the nature of the experiment, being led to believe that the task consisted of adjusting the software (for the low attentional task) and naming the color of words (for the high attentional task). Following the display phase in both conditions, the participants were informed that they had to reproduce the duration of the previously viewed stimulus by pressing the spacebar for the same duration that the stimulus was on the screen. A question mark appeared at the center of the screen as long as the participants pressed the space bar.

The Stroop task was chosen as it is widely acknowledged to reflect attentional processing and its variation in normal aging (e.g., West, 2004) and AD (e.g., Perry and Hodges, 1999). The value of the reproduction design lies in the fact that timing performance mainly depends on cognitive processes (e.g., attention), rather than on other factors such as the speed rate of the internal clock (Mioni et al., 2013), verbal ability (as in verbal estimation tasks), or the ability to compare the relative duration of two intervals (as in time discrimination tasks).

Given that after providing the first retrospective judgment, participants may suspect that further time judgments will be required (turning the paradigm into a prospective one), we took several precautions including 1) spacing the two retrospective tasks one week apart, 2) counterbalancing the procedures in both tasks (i.e., fixating on the cross vs. performing the Stroop task), and 3) preventing the guessing of the real purpose of retrospective tasks by preceeding each task with one of two lure tasks. The latter tasks, also designed with the Psychopy software and presented in the same manner as the retrospective ones, involved participants having to, during the 15s, 1) read aloud a series of numbers and 2) decide whether words were animal or object names. At the end of the display phase, no mention was made of the time reproduction task, also in order to prevent the participants from guessing the real purpose of the forthcoming retrospective tasks.

Performance on time perception was represented by mean time estimate. This variable, referring to the raw score registered for the high attentional and the low attentional task allowed us to compare estimated duration in AD patients and assess whether the former would be underestimated relative to the latter. In order to investigate whether time reproduction in the high and low attentional tasks was significantly shorter than real time, we also calculated the absolute error, or the differences between timings of the high and low attentional tasks and their real time, without regard to sign. It is worth noting that the absolute error is considered a sensitive indicator of time perception deficits in AD (Rueda and Schmitter-Edgecombe, 2009).

2.4. Results: under-reproduction of duration of high attentional task in AD patients.

Figure 1 illustrates the mean time reproduction associated with the high attentional and low attentional load. As Shapiro-Wilk tests (used due to the small sample sizes) showed abnormal distribution for performances in the first ($p < .05$) and second ($p < .001$) task, non-parametric analyses were carried out. For all tests, the level of significance was set at $p < .05$.

For all participants, Wilcoxon signed rank-sum tests revealed that duration of the high attentional task (*M* = 7.69, *SD* = 3.08) was under-reproduced compared to estimation in the low attentional task (*M* = 11.07, *SD* = 3.83) (Z = - 3.96, $p < .001$). This effect was observed in both AD patients (*Z* = - 3.52, $p < .00$), and older adults (*Z* = - 1.98, $p < .05$), but was stronger in AD patients. Wilcoxon signed rank-sum test results also showed a general under-reproduction of time in AD patients (*M* = 7.81s, *SD* = 3.33) compared to healthy older adults (*M* = 10.86, *SD* = 3.75) (*Z* = - 3.67, $p < .001$), with Mann–Whitney U tests revealing the same patterns in the high attentional (*U* = 33.00, $p < .001$) and low attentional (*U* = 84.00, $p < .05$) tasks.

With regard to analyses of the absolute error for the high and low attentional tasks, results showed that the mean reproduction of the duration of high attentional task was significantly shorter than the real time in this task (*M* = 15.00, *Z* = - 5.13, $p < .001$). This pattern was valid for both AD patients (*Z* = - 3.62, $p < .001$), and older adults (*Z* = - 3.63, $p < .001$). The mean reproduction of the duration of low attentional task was also significantly shorter than the real time in this task (*M* = 15.00, *Z* = - 4.03, $p < .001$), a pattern that, once again, was valid for both AD patients (*Z* = - 3.39, $p < .01$), and older adults (*Z* = - 2.16, $p < .05$).

[INSERT FIGURE 1 APPROXIMATELY HERE]

3. Discussion

The main aim of our paper was to investigate how attentional load influences time duration in AD patients. Our results showed that, compared to in the low attentional task, these patients under-reproduced the duration of previously exposed stimuli in the high attentional task.

As such, our findings are in line with the well-established notion that duration judgment decreases as task complexity increases (Dutke, 2005; Zakay and Block, 1996).

Several studies have shown that time moves slowly when we lack activity, and accelerates when we are engaged in complex cognitive tasks and it had been suggested that cognitive activities direct attention from time, decreasing perceived duration (Dutke, 2005). Zakay and Block (1996) implicated an attentional gate that determines how pulses are related to the accumulator while Thomas and Weaver (1975) had described time perception in terms of attentional processing. The latter proposed a negative correlation between the magnitude of stimuli to be processed during a given time interval and perceived duration since stimuli to be processed and time processing compete for attention (Thomas and Weaver, 1975). The present results, showing under-reproduction of duration of the high attentional relative to low attentional task in older adults and AD patients are in line with all of the above assumptions (Dutke, 2005; Thomas and Weaver, 1975; Zakay and Block, 1996).

Critically, the current study is important in showing the influence of aging and Alzheimer’s disease on timing performance. Attentional processing is found to be reliably negatively affected by aging (for a review, see, Verhaeghen and Cerella, 2002), and several authors have associated this deterioration with an acceleration of subjective time (Craik and Hay, 1999; Gruber, et al., 2004). As older adults have limited attentional resources, their perceived duration may shorten, especially in intervals characterized by high attentional processing (Gruber et al., 2004). Because attentional processing is found to be more deteriorated in AD than in normal aging (for a review, see, Perry and Hodges, 1999), it is not surprising that our AD patients showed under-reproduction of the high attentional task than older adults did. Suffering poor attentional processing, these patients might be overwhelmed by the demand of the high attentional task, leaving very few, if any, attentional resources for temporal processing.

Our AD patients under-reproduced the interval of the high attentional more than that of low attentional task, and the interval of the latter task was under-estimated compared to the real time. It is well acknowledged that older adults experience time passing more quickly than younger adults (for a review, see Friedman and Janssen, 2010). Laboratory studies of time perception using the retrospective method have demonstrated that subjective time tends to accelerate with age (for a review, see Friedman and Janssen, 2010). It is not surprising then that our participants, especially AD patients, under-reproduced both high attentional and low attentional tasks relative to their real time. We would argue that the high attentional task requires considerable attentional processing, shortening its subjective duration by AD patients more than the low attentional task. The latter task, requiring few attentional resources (i.e., fixating on the cross) was underestimated by these patients relatively to the real time interval.

The link between timing distortions and attentional decline is supported by an overlap in the neural basis for timing and attention. Clinical reports show a crucial role of frontal lobes in timing mechanisms and attentional processing. Specifically overproduction of duration has been shown in the case of a patient with left frontal tumor (Binkofski and Block, 1996), another patient with a right prefrontal lesion (Koch et al., 2002), and yet another patient with bilateral frontal lobe lesion (Wiener and Coslett, 2008). These clinical reports have been further supported by neuroimaging studies demonstrating activation of the frontal cortex, particularly the right prefrontal cortex, during the processing of suprasecond intervals (for a review, see, Grondin, 2010). Importantly, these frontal regions shown to be associated with timing are heavily implicated in attentional mechanisms. Since the classical work of Hécaen and Albert (1978), reporting attentional deterioration in patients with frontal lobes lesions, many theories support the role of frontal lobes in attention (e.g., Norman and Shallice, 1986; Posner and Petersen, 1990; Knight, 1991; Stuss, 2006), especially right lateral and superior medial frontal areas (for a review, see Stuss, 2006). As the frontal lobes are highly sensitive to aging and given that their alteration is thought to bring about cognitive decline in older adults (e.g., Moscovitch and Winocur, 1995; Raz, 2000; West, 2000), it is perhaps not surprising that attentional deterioration is linked to timing distortions in older adults

Contemporary accounts of the neurophysiological basis of time perception implicate the interactions of a core cortico-thalamic-basal ganglia circuit. This circuit displays different activity dynamics based on context and task and also allows temporal illusions, with, for instance, temporal distortions arising in response to emotionally charged or attention capturing stimuli (Merchant et al., 2013). In one fMRI study in which attention to time was parametrically modulated during a subjective timing task (Coull et al., 2004), increases in attention to time coincided with increases in activation of right temporal cortex, bilateral intraparietal sulcus and putamen. Most importantly to the current study, however, the right premotor and prefrontal cortices were also shown to increase with increased attention to time (Coull et al., 2004). Lesions to the right prefrontal cortex have been associated with timing deficits in longer durations (Danckert et al., 2007 ; Kagerer et al., 2002) and it has been suggested that the right prefrontal cortex uses sensory feedback to continuously update temporal expectations complementing the role of other areas involved in the initial creation of these temporal predictions (Vallesi, 2009). As the frontal lobes are highly sensitive to aging and AD, it is perhaps, therefore, not surprising to see temporal disorders in these populations.

Indeed we argue that, the relationship between timing distortions and attentional decline in AD patients may be interpreted in terms of deterioration in frontal lobe function. More specifically, the great timing deviation in the high attentional relative to the low attentional task, as observed in our AD participants, can be attributed to the fact that the former task required more frontal engagement than the latter one -a suggestion with fits with studies showing important frontal lobe activation during high attentional tasks (for a review, see Stuss, 2006).

On a neurophysiological level, the role of the frontal cortex is believed to be the ‘reading out’ of firing activity of the spiny neurons comprising the cortico-thalamic-basal ganglia timing circuit (Merchant et al., 2013). On a psychological level, however, it has been suggested that frontal activation during time perception may reflect initiation of mental time travel, or the ability to mentally project oneself in time to relive past or future experiences (Tulving, 2002). This assumption was tested in a study (El Haj et al., 2013) showing significant correlations between timing distortions and mental time travel in AD patients, a pattern that was attributed to deterioration in frontal lobe function. Taken together, these outcomes highlight the key role of frontal lobes in timing mechanisms.

A clinical and everyday implication of our findings is that is that cognitive stimulation has the capacity to shorten the subjective experience of time in AD patients and, in doing so, to eliminate any feelings of boredom they might be prone to experiencing. AD patients, especially those institutionalized, tend to complain about monotony, and time stagnation in line with findings that boredom is related to overestimation of the passage of time (Danckert and Allman, 2005). Providing AD patients with activities may decrease their subjective experience of time, enhancing their well-being and contributing to their quality of life.

In summary, our paper extends to AD patients, the well-established notion that directing attention to the passage of time increases perceived duration. It also shows that AD patients, likely due to their deteriorated attentional resources, may experience time as passing even swifter than older adults who have no or less severe attentional deficits.

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Table 1

Demographic and neuropsychological characteristics of Alzheimer's Disease patients and healthy older adults

	Alzheimer	**Older**
Number of participants	17	18
Gender (m/f)	(11/6) $^{n/s}$	(12/6)
Age in years	71.65 (6.53) $^{n/s}$	68.28 (7.90)
Education in years	9.00 (2.55) $^{n/s}$	10.28 (3.14)
MMSE (general cognitive ability)	21.53 (1.77) ***	28.22 (1.59)
Fluency (spontaneous flexibility)	17.47 (5.85) **	23.89 (5.82)
Forward span (working memory)	4.24 (1.25) ***	6.17 (1.42)
Backward span (working memory)	3.53 (1.23) $^{n/s}$	4.17 (1.65)
Five-words (episodic memory)	3.53 (1.28) ***	4.78 (0.43)

Note. MMSE = Mini Mental State Examination, Standard deviations given in parentheses; $^{n/s}$ the difference with the following group was non-significant; the difference between groups was significant at: $^{**}p < .01$, $^{***}p < .001$

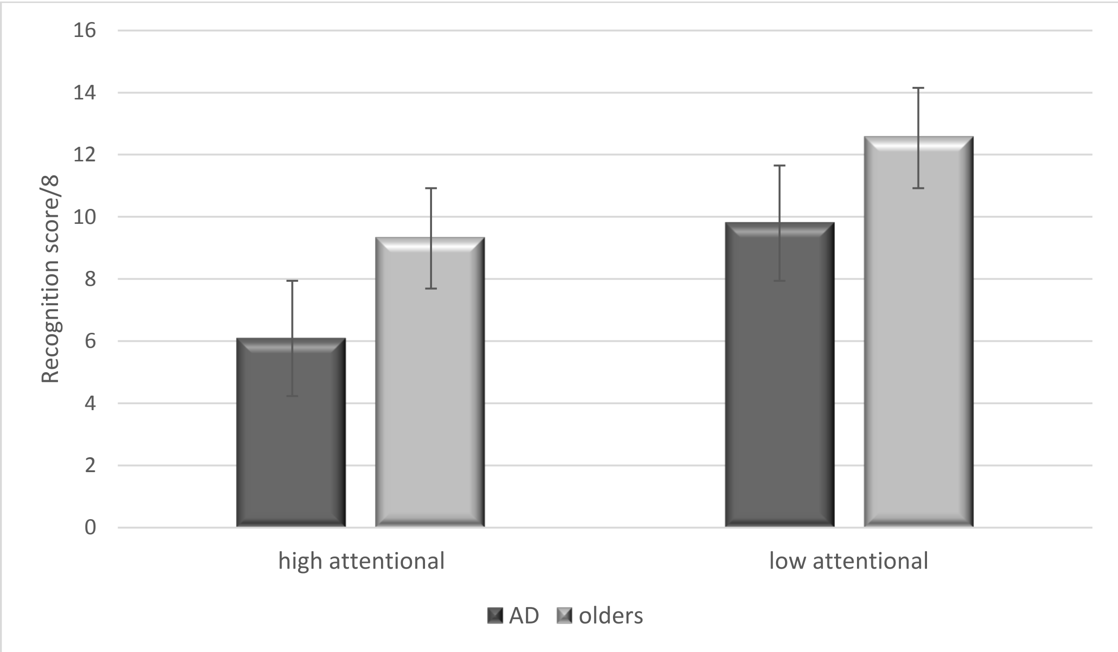

Figure 1

Time reproduction in high attentional and low attentional tasks. Error bars represent standard errors.