The 9 year cognitive decline before dementia of the Alzheimer type: a prospective population-based study

Hélène Amieva,1 Hélène Jacqmin-Gadda,2 Jean-Marc Orgogozo,1,3 Nicolas Le Carret,1 Catherine Helmer,1 Luc Le...
disease and the nature of cognitive processes that are prone to decline first.

In the Framingham cohort, low cognitive performances measured >10 years before dementia onset were found to be predictors of dementia (Elias et al., 2000). Furthermore, measures of linguistic skills assessed 50 years before dementia diagnosis were found to be a risk factor of future Alzheimer’s disease as reported in the Nuns study (Snowdon et al., 1996). Nonetheless, the main limitation of these studies is that they only involved one preclinical measurement point. Thus, it is not possible to establish whether the low performances of pre-morbid subjects were related to a real decline in cognitive function that could be in favour of a long-term ongoing pathological process, or to a baseline status of poor cognitive function that could be in favour of a long-term ongoing process of pre-morbid subjects were related to a real decline in cognitive function that could be in itself a risk factor for the future Alzheimer’s disease and the nature of cognitive processes that are prone to decline first.

In the Framingham cohort, low cognitive performances measured >10 years before dementia onset were found to be predictors of dementia (Elias et al., 2000). Furthermore, measures of linguistic skills assessed 50 years before dementia diagnosis were found to be a risk factor of future Alzheimer’s disease as reported in the Nuns study (Snowdon et al., 1996). Nonetheless, the main limitation of these studies is that they only involved one preclinical measurement point. Thus, it is not possible to establish whether the low performances of pre-morbid subjects were related to a real decline in cognitive function that could be in favour of a long-term ongoing pathological process, or to a baseline status of poor cognitive function that could be in itself a risk factor for dementia. In the study of Rubin et al. (1998), 82 elderly volunteers were assessed repeatedly during a 15 year follow-up. Before the onset of dementia, the cognitive changes between the future Alzheimer’s disease subjects and those remaining free of dementia were not different except for the Wechsler Logical Memory subtest, although when the cognitive decline began, an abrupt and general deterioration of performances was observed. However, the comparability of these results with those previously cited is difficult since the diagnostic outcome was a clinical dementia rating score greater than 0 which includes very mild cognitive impairment instead of the more conservative DSM-IV criteria for dementia.

Concerning the nature of cognitive processes that deteriorate early in dementia, it is usually considered that loss of episodic memory is the core feature of the dementing process (Small et al., 2000; Bäckman et al., 2001; Albert, 2002). It is, however, worth noting that numerous studies have shown that other domains of cognition are also impaired in the preclinical phase of Alzheimer’s disease (Masur et al., 1994; Jacobs et al., 1995; Linn et al., 1995; Dartigues et al., 1997; Howieson et al., 1997; Fabrigoule et al., 1998; Schmand et al., 2000) and that some of these cognitive deficits may be the cause of slight impairments on instrumental activities of daily living (Barberger-Gateau et al., 1999).

Personal and socio-demographic factors such as age or gender seem to have an influence on the occurrence of dementia and the course of decline (Letenneur et al., 1999). Education is also an important factor (Katzman et al., 1993; Letenneur et al., 1999; Karp et al., 2004). Its influence is often explained by the hypothesis that people with high educational level have a greater ‘cognitive reserve capacity’ than people less educated (Stern et al., 1994). This so-called ‘cognitive reserve’ would be due to positive effects of early education on cerebral and cognitive development and would therefore delay in later life the clinical manifestations of dementia by compensating the cognitive expression of the pathology. It is therefore mandatory to take these factors into consideration when interpreting any cognitive decline occurring prior to the diagnosis of Alzheimer’s disease in elderly adults.

The focus of this report is to describe the decline of cognitive functioning occurring in the preclinical period of Alzheimer’s disease. With the long follow-up of the Paquid study (Dartigues et al., 1992), we have had the opportunity to investigate this decline over 9 years with serial measurements of global cognitive performances, verbal fluency, abstract thinking and visuo-spatial memory obtained at five time points of the follow-up.

**Methods**

**Participants and follow-up**

The detailed methodology of the Paquid study has been presented previously (Dartigues et al., 1992). Briefly, Paquid is a population-based study made up of 3777 elderly adults aged ≥65 years, living at home in the South-western part of France (Gironde and Dordogne) at enrolment. Individuals were seen at home by psychologists trained in home interviews at the initial visit (V0) and at 1 (V1), 3 (V3), 5 (V5), 8 (V8) and 10 years (V10) after the initial visit in Gironde and the same, except for the 1 year visit, in Dordogne. Each visit included a neuropsychological evaluation and a standardized diagnosis of dementia. This cohort is part of an epidemiological programme on ageing, particularly focused on the incidence, natural history and non-genetic risk factors of dementia.

**Neuropsychological measurements**

Four neuropsychological tests were systematically proposed to the subjects at each visit: a French version of the Mini-Mental Status Examination (MMSE) (Folstein et al., 1975) was used as an index of global cognitive performance. The multiple choice recognition form of the Benton Visual Retention Test (BVRT) (Benton, 1965) was used to measure visual memory (scores range from 0 to 15). The Isacs Set Test (IST) (Isacs and Kennie, 1973) assessed verbal fluency by measuring the ability to generate lists of words in four semantic categories (colours, animals, fruits and cities) in a 15 s interval. We stopped the counting if the subject generated >10 words in each category, thus possible scores ranged from 0 to 40. Finally, the Similarities subtest of the Wechsler Adult Intelligence Scale (WST) (Wechsler, 1981) assessed abstract thinking by measuring the ability to find in what way two things are alike (e.g. ‘orange–banana’). Only the first five pairs of the subtest were considered, so possible scores ranged from 0 to 10.

In addition to the neuropsychological examination, the psychologists recorded socio-demographic factors, measures of functional abilities assessed with the Instrumental Activities of Daily Living (Lawton and Brody, 1969) and the Activities of Daily Living (Katz, 1983) scales, depressive symptomatology and a medical questionnaire including health measures, self-reported morbidity and medication.

**Dementia diagnosis**

According to this evaluation, the psychologists completed a standardized questionnaire designed to obtain the A (memory impairment), B (impairment of at least one other cognitive function) and C (interference with social or professional life) DSM-III-R criteria for dementia. Individuals who met criteria for dementia as well as those presenting a decline of 3 points or more on the MMSE since the previous visit were seen by a senior neurologist who was not informed about the cognitive scores obtained by the subjects during their interview with the psychologist. The neurologist confirmed dementia criteria and assessed the NINCDS-ADRDA criteria.
Sample

The aim of this work is to compare the cognitive change over time of future Alzheimer’s disease subjects in the 9 years preceding the diagnosis with that of subjects remaining non-demented until the 10 year visit of the Paquid study. For this analysis, the 1 year visit (V1) was considered as the baseline and thus cognitive measures collected at V0 were not included. Indeed, in previous analyses, we have shown a test–retest improvement between V0 and V1 (Jacqmin-Gadda et al., 1997). This may be explained either by a practice effect or by a stress effect due to the testing situation which was new for the subjects at V0. Inclusion of the V0 scores would have required adding a parameter in the model (the V0 effect) without increasing the precision of the other parameters.

We have compared two samples. To be included in the Alzheimer’s disease sample, subjects had to be: (i) non-demented at the baseline visit (V1); (ii) diagnosed with Alzheimer’s disease during the 9 years of follow-up after baseline (i.e. at V3, V5, V8 or V10); and (iii) seen at the last visit preceding the diagnosis.

As the period of time directly preceding the occurrence of dementia is crucial in this type of analysis, condition (iii) was added to obtain an accurate estimate of the time of dementia onset and of the evolution of the cognition in the last years preceding the diagnosis. Among the 320 subjects diagnosed with Alzheimer’s disease after V1, 215 were seen at the previous visit and thus were included in the sample. Subjects diagnosed with other types of dementia were not included (48 vascular dementia, 34 Parkinson dementia and 14 other dementias).

To be included in the sample of normal controls, subjects had to be: (i) seen and free of dementia at the 10 year follow-up (V10); and (ii) seen at the 8 year visit (V8). Condition (ii) was used to mimic condition (iii) of the Alzheimer’s disease sample and make the selection procedure as similar as possible for the two samples. Thus, among 1201 subjects considered as free of dementia at V10, 148 subjects were not seen at V8 and three other subjects were excluded because they performed none of the tests during the 9 years of follow-up, leading to a sample of 1050 subjects without dementia. Table 1 describes demographic and health characteristics of the two samples.

Outcome variables

For each of the four neuropsychological tests described above, cognitive change over time was estimated separately on the sample of Alzheimer’s disease subjects and on the sample of individuals without dementia. The outcome variables were repeated measurements of the test scores collected between the baseline visit and the visit of diagnosis for the Alzheimer’s disease cases and between the baseline visit and the 10 year follow-up for those without dementia. Measures collected after the visit of diagnosis were not used.

Explanatory variables

For Alzheimer’s disease cases, we studied cognitive change as a function of the time interval between each measurement occasion and the date of diagnosis. For subjects without Alzheimer’s disease, the cognitive change was studied as a function of the time interval between each measurement occasion and the 10 year follow-up. Thus, for both samples, the value of the time variable ranges from −9 years to 0. Time 0 is the date of diagnosis for Alzheimer’s disease cases and the 10 year follow-up for subjects not developing dementia.

Covariates taken into account were gender, age at time 0 (diagnosis or 10 year follow-up) in two classes defined by the median age at diagnosis for incident cases (86 years) and educational level (no diploma versus primary school diploma or higher level). This categorization for education was found previously to be the best education-related predictor of dementia in the Paquid study (Letenneur et al., 1999).

Statistical model

The linear mixed model (Laird and Ware, 1982) is one of the standard models to evaluate longitudinal change of an outcome measured repeatedly over time because it takes into account the correlation between repeated measures on the same subjects. Moreover, this

| Table 1 Demographic and health characteristics of subjects at entry in the Paquid cohort |
|----------------------------------------|----------------------------------------|
| Age at diagnosis or 10 year follow-up | Non-Alzheimer’s disease subjects (n = 1050) % | Alzheimer’s disease subjects (n = 215) % |
| <86 | 80.5 (n = 845) | 50.2 (n = 108) |
| ≥86 | 19.5 (n = 205) | 49.8 (n = 107) |
| Sex | | |
| Men | 39.3 (n = 413) | 28.4 (n = 61) |
| Women | 60.3 (n = 637) | 71.6 (n = 154) |
| Educational level | | |
| No diploma | 22.7 (n = 238) | 49.3 (n = 106) |
| Primary school with diploma or + | 81.3 (n = 812) | 50.7 (n = 109) |
| Rural place of residence | | |
| Tobacco consumption | | |
| Smoker | 9.2 | 8.0 |
| Ex-smoker | 25.5 | 16.0 |
| Non-smoker | 65.3 | 76.0 |
| Diabetes | 6.8 | 8.9 |
| History of stroke | 0.57 (n = 6) | 2.82 (n = 6) |
| History of head trauma | 13.5 | 11.6 |
| Angor | 17.0 | 20.7 |
| Myocardial infarction | 10.1 | 9.8 |
| Angina | 14.9 | 10.8 |
| HTA | 14.7 | 21.4 |
method allows analysis of repeated data with unequal numbers and
times of measurements per subject and is robust against data missing
at random. However, a drawback of this model is that it assumes a
parametric form (generally linear or polynomial) for the change over
time, while we suspect that cognition in the pre-diagnosis phase of
dementia has a non-linear evolution with an acceleration of the
delay just before the diagnosis. As we are particularly interested
in the shape of the cognitive decline before the diagnosis of demen-
tia, we used a semi-parametric extension of the linear mixed model
which requires no a priori assumption on the shape of this curve
(except that it is smooth, i.e. without very abrupt changes). Details
on the statistical method are given in Jacqmin-Gadda et al. (2002).
The curves were estimated for each sample (Alzheimer’s disease or
non-Alzheimer’s disease subjects) and, to avoid making assumptions
about the impact of covariates on the shape of the curve, the curves
presenting cognitive change over time of Alzheimer’s disease and
non-Alzheimer’s disease subjects were re-estimated separately for
each age group, each gender and each educational level. Sample
sizes for each subanalysis are reported in Table 1. Computation of
95% confidence bands for each curve allows comparison of the
curves for each group. In all analyses, the correlation between
responses of the same subject is assumed to have an auto-regressive
structure, i.e. the correlation decreases exponentially with the delay
between measurements.

Results
The mean age at inclusion in the Paquid cohort was 71.9
(SD = 5.0) for the 1050 individuals without Alzheimer’s
disease and 78.7 (SD = 6.1) for the 215 pre-morbid subjects.
The proportion of subjects with a low level of education was
22.7% among the subjects not developing dementia and
49.3% among the future Alzheimer’s disease subjects.
Other characteristics are shown in Table 1. Among the 215
Alzheimer’s disease cases, 38 were diagnosed at the 3 year
follow-up, 43 at 5 years, 44 at 8 years and 91 at the 10 year
follow-up.

The age at diagnosis was not significantly different for the
215 Alzheimer’s disease cases included (86.0, SD = 6.0) and
the 105 cases excluded because they were not seen at the visit
preceding the diagnosis (84.8, SD = 5.8, P = 0.10). These two
groups were different neither in gender and educational level
nor in the scores on the MMSE, BVRT and IST at the pen-
lultimate visit before diagnosis. However, excluded subjects
had a lower mean score at diagnosis for the MMSE (P =
0.001) and IST (P = 0.05), suggesting, as expected, that these
subjects had been demented for a longer time. They also had a
higher rate of missing data at the time of diagnosis.

Age and gender were found to have little influence on test
scores so only the influence of Alzheimer’s disease status and
educational level are presented in the following section.

Change in the MMSE score
Figure 1A displays the estimated mean change over time of
the MMSE score for the sample of Alzheimer’s disease cases
and the sample of individuals without Alzheimer’s disease.

![Fig. 1 Estimated evolution of the mean MMSE score (and
95% confidence bands) during the 9 years preceding the last visit
(for non-Alzheimer’s disease cases) or the diagnosis (for
Alzheimer’s disease subjects). (A) Whole sample: red curve,
non-Alzheimer’s disease cases; blue curve, Alzheimer’s disease
cases. (B) Non-Alzheimer’s disease cases according to
educational level: yellow curve, non-Alzheimer’s disease cases
with high education level; red curve, non-Alzheimer’s disease
cases with low education level. (C) Alzheimer’s disease subjects
according to educational level: pale blue curve, Alzheimer’s
disease cases with high education level; dark blue curve,
Alzheimer’s disease cases with low education level.](image)
Among the latter, the mean MMSE score decreased very slightly over the 9 years, from 27.6 to 26.9. Nine years before the diagnosis, the score of the pre-morbid cases was already lower than that of individuals without dementia 26.2 versus 27.6. Between T–9y and T–3y, the score of Alzheimer’s disease subjects decreased more than that of subjects without Alzheimer’s disease, with an approximated slope of 0.32 point per year. Between T–3y and T0, their score decreased much faster, with a slope of ~2.2 points per year. Thus, throughout the 9 years preceding the diagnosis, subjects who would develop Alzheimer’s disease had a faster decline of the MMSE score than subjects without Alzheimer’s disease, with an acceleration of this decline ~3 years before the diagnosis. Figure 1B and C displays the change over time of the MMSE score according to educational level for the individuals without dementia and the future Alzheimer’s disease cases, respectively. Figure 1B shows that subjects without Alzheimer’s disease with low educational level have a lower score but a similar cognitive change over the 9 years than those with higher education. On the contrary, Fig. 1C shows that education has an important impact on the pattern of evolution of the MMSE score in the future Alzheimer’s disease cases, subjects with high educational level having a sharper decline in the 4 years preceding the diagnosis of Alzheimer’s disease.

Change in the BVRT score

Figure 2A displays the estimated change over time of the BVRT score for the sample of Alzheimer’s disease cases and the sample of subjects without dementia. The mean BVRT score of non-Alzheimer’s disease subjects decreased very slightly from 11.5 at T–9y to 11.0 at T0, and their score at T–9y was higher than that of the future Alzheimer’s disease subjects (9.7) without overlap of confidence intervals. The decline of BVRT score in the future Alzheimer’s disease subjects appeared to be more regular than for the MMSE, with a less abrupt acceleration of the decline after T–4y (change of slope from ~0.14 point per year between T–9y and T–4y to 0.56 point per year between T–4y and T0). Figure 2B and 2C displays the estimated change on the BVRT according to educational level for the subjects without Alzheimer’s disease and the pre-morbid cases, respectively. Whatever the Alzheimer’s disease status (Fig. 2B and C), subjects with a low educational level had a lower estimated score at T–9y than their more educated counterparts. Among the subjects without Alzheimer’s disease (Fig. 2B), the evolution is parallel for the two educational level groups. Among the future Alzheimer’s disease subjects (Fig. 2C), the decline before diagnosis appears nearly linear in less educated subjects, while highly educated subjects show a dramatic increase in the rate of decline ~3 years before the diagnosis.

Change in the IST score

Figure 3A displays the estimated change over time of the IST score for the sample of Alzheimer’s disease cases and the
sample of individuals without Alzheimer’s disease. Figure 3B and C presents the curves according to educational level for the normal controls and the future Alzheimer’s disease subjects, respectively. The IST scores decreased, with some minor fluctuation over time, from 30.5 to 26.5 in subjects not developing dementia (Fig. 3A). Their baseline score was higher than that of the future Alzheimer’s disease subjects (26.5) without overlap of confidence intervals. The decline of IST scores in the future Alzheimer’s disease subjects was steeper and more regular than that of BVRT, with only a slightly more rapid decline at the end of the course. The score of the future Alzheimer’s disease subjects declined faster in highly educated than in less educated subjects (Fig. 3C).

**Change in the WST score**

Figure 4A displays the estimated change over time of the WST score for the sample of Alzheimer’s disease cases and the sample of subjects without Alzheimer’s disease. Figure 4B and C presents the estimated curves according to educational level for the normal controls and the future Alzheimer’s disease subjects, respectively. In non-Alzheimer’s disease subjects, the WST score decreased very slightly from 7.2 to 6.8 and their T–9y score was higher than that of the future Alzheimer’s disease subjects (6.4) without overlap of confidence intervals (Fig. 4A). In the future Alzheimer’s disease subjects, the WST score declined almost linearly from 6.4 at T–9y to 3 at T0. Among the Alzheimer cases, Fig. 4C shows that more educated subjects had a higher score all along the 9 years preceding the diagnosis and declined faster than less educated subjects in the 3 years preceding the diagnosis.

**Discussion**

This descriptive approach of the time course of well established markers of cognitive functioning up to 9 years before Alzheimer’s disease onset allows validation and quantification of the assumption that a long-lasting and progressive preclinical phase exists before the clinical onset of dementia. Three sets of results came out of the present study.

Few cohort studies have analysed more than one measurement point before dementia and could be compared with our results. In the MoVies Study, Chen et al. (2001) showed that several cognitive measures assessed in elderly people who would later become demented decreased between 3.5 and 1.5 years before dementia onset. The Kungsholmen project (Bäckman et al., 2001) showed that tasks of episodic memory were impaired 3 and 6 years before the occurrence of dementia. The Bronx cohort (Hall et al., 2001) analysed cognitive decline up to 15 years before dementia in 75 cases of probable Alzheimer’s disease and mixed dementia. It showed an accelerated memory decline starting 7 years before dementia diagnosis. However, mixed dementia was included in the outcome point, so that additional deficits related to stroke
may have interfered with the course of the decline due to Alzheimer’s disease, which could explain this difference from our findings (decline during only 7 versus at least 9 years).

Secondly, the course of cognitive decline before dementia is clearly related to education. Highly educated subjects had higher performances at T–9y and experienced a faster decline in the few years preceding dementia, so that their performances joined the curves of the less educated subjects. This non-linear decline suggests more a greater ‘cognitive reserve capacity’ in highly educated subjects than a true protective effect of education against Alzheimer’s disease. The exhaustion of this ‘reserve capacity’ in highly educated subjects may well account for the accelerated decline which occurs in the 3 years preceding the detection of dementia.

Thirdly, our results confirmed that not only episodic memory tasks are impaired long before the onset of dementia syndrome, as previously suggested (Masur et al., 1994; Jacobs et al., 1995; Linn et al., 1995; Dartigues et al., 1997; Howieson et al., 1997; Fabrigoule et al., 1998; Schmand et al., 2000). Over a more extended 22 year surveillance period, a study from the Framingham cohort (Elias et al., 2000) showed that low scores of verbal memory and abstract thinking (assessed by the WST) were predictive of the onset of Alzheimer’s disease 10 years after baseline assessment. We also found the WST and a test of memory, albeit although visuo-spatial memory, to be predictive of future dementia occurring at a comparable delay. The course of decline in future Alzheimer’s disease patients seems to be different across the tests. This could be explained by the differences in the metrological properties of the tests. For the MMSE, the acceleration of the decline could be due to the fact that this test is taken as an indicator of cognitive deterioration in the NINCDS-ADRDA criteria and thus was used for the purpose of diagnosis in the Paquid study. So it is not unexpected that an important decline in MMSE score was observed between the last visit at which a subject was considered as non-demented and the visit at which the subject was classified as an incident case of Alzheimer’s disease. However, a similar acceleration of decline was observed over the same period (or even before), at least in highly educated subjects, with other tests measuring cognitive functions not assessed in the MMSE, i.e. visuo-spatial memory, verbal fluency and abstract thinking. Thus the change in speed of cognitive decline 3–4 years before the clinical diagnosis of Alzheimer’s disease may be a real phenomenon. In the Kungsholmen study, there was no evidence of accelerated decline of memory from 6 to 3 years before dementia diagnosis. In this study, however, only 15 future Alzheimer’s disease subjects were followed-up and the memory performances were actually slightly lower at T–3y than at T–6y (Bäckman et al., 2001).

One limitation of this study is due to the attrition of the cohort. Indeed, the group of individuals without Alzheimer’s disease consists of subjects alive and seen at the 8 year and 10 year visits. As we have previously shown that drop-out in the Paquid cohort was associated with lower MMSE scores (Jacqmin-Gadda et al., 1997), it is likely that included...
non-Alzheimer’s disease subjects have slightly higher neuro-psychological performances than excluded ones. On the other hand, to be included, Alzheimer’s disease subjects had to be diagnosed before their drop-out. Among subjects who satisfied the above conditions, all those having completed at least one cognitive test during the follow-up were included. The inclusion of subjects with incomplete data limits possible biases due to attrition. Indeed, analyses are unbiased if non-responses to cognitive tests are associated with previously observed scores but independent from the current missing scores (missing at random assumption). If subjects with incomplete measures had been excluded, the hypothesis that non-responses are completely independent from past and current cognitive performances would have been required (missing completely at random assumption) and we have shown previously that this hypothesis is false (Dartigues et al., 1997; Jacqmin-Gadda et al., 1997).

Two non-exclusive patho-physiological models could explain the patterns of evolution of cognitive performances in future Alzheimer’s disease patients observed in this study. The first possible model would postulate that the pathological process of Alzheimer’s disease does begin >8–9 years before its clinical stage. During an initial period, cognitive decline is slow, expressing the balance between the progression of the pathological process (Delacourte et al., 2002) and the biological, psychological or environmental mechanisms of compensation (Armstrong and Barker, 2001). In a second phase, cognitive decline accelerates, due either to the failure of compensatory mechanisms or to a faster progression of the pathological process. In the second model, the pathological process occurs only 3–4 years before the clinical expression of Alzheimer’s disease and explains the accelerated cognitive decline. The first period of cognitive decline would then be explained by the effect of exposure to risk factors for Alzheimer’s disease, such as low education levels or old age, or by as yet unidentified causes of cognitive decline that may accelerate the clinical expression of Alzheimer’s disease such as vascular brain damage (Wermier et al., 2003). The difference between these models could have important implications for preventive strategies for this disease. In the first model, the best time for preventive strategies would be the first period of decline, in order to arrest the disease process or enhance compensatory mechanisms. In the second model, the best time for treatment would be the second period of fast decline, to interfere directly with the pathological process. The present findings are more in favour of the first model since, after adjusting for the effect of known risk factors, especially education, the early decline of cognitive function remained faster in pre-morbid subjects than in individuals without the disease.

References
Nine year cognitive decline before dementia


