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Higher mental stimulation at work is associated with improved cognitive functioning in both young and older workers

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The study examined whether mental stimulation received in the workplace positively affects cognitive functioning and rate of cognitive change. Data taken from the VISAT (ageing, health and work) longitudinal study concerned 3237 workers who were seen three times (in 1996, 2001 and 2006) and who were aged between 32 and 62 years at baseline. Measures of cognitive stimulation both at work and outside work were available at baseline. Cognitive efficiency was assessed on the three occasions through episodic verbal memory, attention and processing speed tests. Greater cognitive stimulation (at work and outside work) was associated with higher levels of cognitive functioning and a more favourable change over the 10-year follow-up. These results were obtained after adjustment for age, education, sex and a variety of medical, physical and psychosocial confounders. The study thus supports the hypothesis that exposure to jobs that are mentally demanding and that offer learning opportunities increases the level of cognitive functioning and possibly attenuates age-related decline.

Statement of Relevance: The effect of occupational activity on cognitive functioning is under-researched. This paper reports results from a substantive longitudinal study, with findings indicating that exposure to jobs that are mentally demanding are beneficial in increasing levels of cognitive functioning and possibly attenuating age-related decline.

Keywords: ageing; cognitive performance; cognitive stimulation; longitudinal study; mental demand; work

1. Introduction

The goal of the present study was to examine the extent to which cognitive characteristics of the occupational environment have an impact on the level of cognitive functioning and the rate of cognitive change in adults of various ages. In the literature on occupational psychology and ergonomics, jobs involving poor cognitive activities have often been suspected of generating some forms of cognitive decline. This idea of a possible detrimental (or favourable) effect of the job on the worker's psychological functioning, even on basic cognitive processes, has long been formulated in human and social sciences (e.g. Friedman 1964). Although this idea is both appealing and popular, there has so far been little empirical evidence to support it, from the viewpoint of impact on cognition.

One exception is the study by Schooler *et al*. (1999, see also Kohn and Schooler 1978), which provides direct evidence in favour of the hypothesis that cognitive (or mental) stimulation at work yields beneficial effects on adult cognitive development. These authors found a relationship between intellectual functioning and the cognitive complexity of the work environment. Their findings suggest that substantively complex work significantly increases intellectual flexibility. They defined substantive complexity of work as work on things, data or people with varied stimuli, which in its very substance requires thought, independent judgements and numerous decisions involving ill-defined or apparently contradictory contingencies. Finkel *et al*. (2009), using similar measures of job complexity in a cohort of 462 participants, found evidence indicating that, after controlling for education, only complexity of work with people was associated with improved performance in verbal skills. In the cross-sectional study by Andel *et al*. (2007), it was the complexity of work with data and people that showed an association with cognitive function. In a follow-up study of approximately 7 years, Potter *et al*. (2006) also found evidence indicating that greater intellectual demand at work resulted in more stable cognitive performance in old age. Finally, Bosma *et al*. (2003) obtained results suggesting that the mental demands of work protected a population of men and women aged between 50 and 80 years against cognitive impairment.

Apart from these few studies, which explicitly focus on the effects of work, there is only indirect evidence in

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favour of the view that occupational cognitive experiences influence adult cognitive development. Such evidence mainly comes from the literature on cognitive ageing and widely refers to the so-called 'disuse' perspective. According to this perspective, age-related changes in cognitive efficiency are accounted for, at least in part, by changes in the amount of cognitive activity during adulthood. Not using certain cognitive processes can result in the functional atrophy of those processes. This idea, neatly summed up in the saying 'use it or lose it' (Swaab 1991), has often been put forward as an a posteriori explanation of age-related differences, older people being assumed to perform less well because of less recent experience in the relevant tasks. The differential preservation or maintenance hypothesis expresses the same idea but in a positive way: intensive and durable use of specialised cognitive processes during adult life, as in many jobs, may preserve these processes from the age-related decline usually observed (Salthouse 1991, 2006, Marquié 1997, see also Goldspink 2005) in the physical domain. Results obtained in neuroscience in the last 20 years lend support to this view by showing that adult brain plasticity is proving to be greater than expected so far (e.g. Kolb *et al.* 1998).

Some studies used composite measures of activity or engaged lifestyle that make it impossible to estimate the specific contribution of mental activity in the reported results (e.g. Aartsen *et al.* 2002, Richards *et al.* 2003). Among the studies that can be used to estimate the specific influence of mental activity on the level of cognitive functioning, some referred to leisure cognitive experiences only (Schooler and Mulatu 2001, Crowe *et al.* 2003, Singh-Manoux *et al.* 2003, Karp *et al.* 2006). Other studies referred to general cognitive activities, i.e. activities not specifically related to leisure or occupational domains, such as reading, writing, driving or using computers, either as a unique factor (Gold *et al.* 1995, Salthouse *et al.* 2002, Cohen *et al.* 2008) or as a factor among other lifestyle factors, such as physical exercise or social activities (Christensen and Mackinnon 1993, Hultsch *et al.* 1999, Newson and Kemps 2005, Fritsch *et al.* 2007, Yaffe *et al.* 2009). Some of these studies were successful in demonstrating a significant association between intellectual-cultural activities and a higher level of cognitive functioning (Schooler and Mulatu 2001, Singh-Manoux *et al.* 2003). In other studies, only partial evidence was obtained, as in the Crowe *et al.* (2003) study, which showed a lower risk of Alzheimer's disease for women but not for men, or in the Christensen and Mackinnon (1993) study, where the same association was found only for low levels of education. A third category of studies failed to find evidence in favour of the positive effect of everyday cognitive practice (e.g. Gold *et al.* 1995, Salthouse *et al.* 2002, van Dijk *et al.* 2008) or were not fully conclusive (Hultsch *et al.* 1999).

There is clearly still conflicting evidence as to whether engaging oneself in mentally stimulating activities is associated with higher cognitive functioning and predicts more favourable cognitive development in adulthood. Evidence is even scarcer, as stated above, when specifically considering the effects of occupational cognitive experiences. Having data on this issue, however, would be highly desirable in order to understand how a person's job contributes to the development or alteration of cognitive efficiency and to formulate intervention strategies that minimise detrimental consequences of work organisation on the individual. Working life covers more than 40 years of adult life and represents a major source of cognitive experience in adulthood. It is argued that both its quantitative and qualitative importance in accounting for psychological development in a person's later years has been underestimated in earlier work.

In the current study, the assumption that mental stimulation at work has an impact on both the level of cognitive functioning and the rate of cognitive change was tested using data taken from the large-scale 'Vieillissement, Santé, Travail' (in French; VISAT) longitudinal study of the relationships between ageing, health and work (Marquié *et al.* 2002). The effect of cognitive stimulation in the workplace was examined using a statistical approach based on linear mixed models (Verbeke and Molenberghs 2000). This statistical method offers many advantages and is well suited to these data, especially as it can be used to look at cross-sectional and longitudinal effects in one single analysis. In addition to the effects of occupational cognitive experiences, the possible influence of other activities were also controlled for, such as leisure cognitive activities, social engagement and physical exercise, whose potential impact was suggested by earlier findings (Seeman *et al.* 2001, Richards *et al.* 2003, Kramer *et al.* 2005). A number of other factors, such as education, sex and health, are also known to have a possible influence on the level of cognitive efficiency and must be controlled (Fritsch *et al.* 2007, see also Schaie and Abeles 2008).

The effects of occupational cognitive experience on performance were examined through various cognitive tests. It was expected that more mentally stimulating occupational environments would be associated with higher levels of cognitive functioning and more favourable cognitive change over the 10-year follow-up, irrespective of other demographic, health and lifestyle influences. The hypothesis that stimulation at work attenuates age-related decline should be reflected in an interaction between cognitive stimulation and age at baseline. However, as age reflects not only the ageing process but also possible historical and cohort influences, the ultimate support for the hypothesis in a prospective design and in a linear-mixed-models approach would be an interaction between test occasion and stimulation. A three-way interaction between age, test occasion and stimulation could also be expected, which would mean that the protective effect of cognitive stimulation would be relatively more pronounced for the older participants.

2. Method

2.1. *Participants*

Data were taken from the VISAT longitudinal study (to find out more about the goals and general methodology of this study, see Marquié *et al.* 2002). The original sample consisted of 3237 healthy men and women who were current or former wage earners of all levels of education and all occupational classes. They were born in 1964, 1954, 1944 and 1934 and were thus exactly 32, 42, 52 and 62 years old respectively at the time of the first data collection (1996, also called baseline or t1). Only the group born in 1934 included retirees (83%). Participants were randomly drawn from among the patients of 94 occupational physicians in three southern regions of France, who volunteered for VISAT. The participation rate was 76% in 1996. Among the 3237 participants in 1996, 70.7% were seen in 2001 and 40.4% in 2006. In total, 79 (2.4%) participants who reported diabetes mellitus and 35 (1.1%) participants with missing values were not included in the analyses, thus resulting in a final studied sample of 3123 participants. Data were collected during the annual medical examination, which is part of the health screening programme that takes place within the company. All participant physicians were trained to ensure standardisation of data collection. Retired workers who were no longer being monitored by the occupational physicians were specially invited for the purpose of the study. The characteristics of the sample are shown in Table 1.

2.2. *Material and procedure*

2.2.1. *Cognitive tests*

Cognitive functioning was assessed in all participants on the three measurement dates (1996, 2001, 2006) through eight cognitive tests. They were administered in the following order: (i) three word-list learning/recall tests; (ii) the WAIS digit symbol substitution subtest; (iii) two selective attention tests; (iv) two

Table 1. Participants' characteristics at baseline, cognitive performances and correlations with SAW and STIMGEN.

			Spearman's rho	
	n (%)	Mean ± SD	SAW	STIMGEN
Age at baseline (years)		44.68 ± 10.2	–0.05**	–0.08**
32	886 (28.4)			
42	952 (30.5)			
52	848 (27.2)			
62	437 (14.0)			
Total	3123 (100)			
Sex			–0.02	0.095**
Men	1590 (50.9)			
Women	1533 (49.1)			
Education (years)		11.65 ± 3.6	0.36**	0.432**
Perceived health (0–10)		7.15 ± 2.0	0.05**	0.041*
Systolic blood pressure (mm Hg)		129.0 ± 15.2	–0.06**	–0.088**
BMI (kg/m^2)		24.63 ± 3.9	–0.06**	–0.113**
Perceived stress (score: 0–16)		4.44 ± 3.0	–0.05**	–0.039**
Physically active sports (yes)	1661 (53.2)		0.11**	0.17**
Social activity (yes)	1317 (42.2)		0.12**	0.16**
Cognitive stimulation outside work (score: 0–2)		0.80 ± 0.8	0.19**	0.72**
Cognitive performance (factorial score)				
Baseline		–0.23 ± 2.4	0.26**	0.34**
First follow-up		0.29 ± 2.4	0.22**	0.27**
Second follow-up		0.32 ± 2.5	0.24**	0.31**
Follow-up				
2001	2214 (70.9)			
2006	1274 (40.8)			

SAW = cognitive stimulation at work; STIMGEN = general cognitive stimulation (at work and outside work).
*$p \leq 0.05$; **$p \leq 0.01$.

delayed retrieval tests (free recall and recognition) based on the material learned earlier.

The word-list learning/recall test consisted of three trials, each followed by immediate free recall. This test was an adapted version of the Rey auditory verbal learning test (Rey 1964). The words were two-syllable, frequent and phonetically unambiguous common nouns. The WAIS Digit Symbol Substitution Test (Wechsler 1955) is considered highly loaded in its information-processing speed component and very sensitive to the effects of ageing (Salthouse 1992). The next two tests were selective attention tests derived from Sternberg's test (Sternberg 1975). The first involved scanning a line of 58 alphabetic characters as quickly as possible to find a target letter shown in the margin and then crossing it out. This task was repeated six times with a different target each time. The second subtest also had six lines of 58 alphabetic characters, but this time the memory load was greater because the aim was to locate one of the four letters shown in the margin. The two delayed retrieval tests included a free recall test and a recognition test. In the free recall test, the participant was required to name correctly as many words as he/she could from the 16 previously learned words. In the recognition test, the participant was asked to rate the 16 previously learned words, which were randomly mixed in with 32 new words (distractors).

For the five memory tests (three learning/immediate free recall trials, delayed free recall and recognition) results were given as the number of words correctly recalled, or rated in the case of the recognition test. Results concerning the Digit Symbol Substitution Test were given as the number of symbols correctly copied in 90 s. Results concerning the two selective attention tests were given as the time taken to perform the test, but this time the value was reversed using the following equation:

$$x_{i(max)} - x_i, \quad (1)$$

where $x_{i(max)}$ was the highest value of all participants' values. Thus, higher values of selective attention scores reflected higher cognitive performance, as for the other cognitive tests.

A principal component analysis was conducted on the eight cognitive performances. The first factor accounted for 53.4% of the total variance. It was interpreted as a general performance axis. The second factor accounted for 14.8% of the total variance and tended to contrast memory-oriented tests with speed-oriented tests. The next three factors accounted for 8.0%, 6.6% and 6.3%, respectively. A new cognitive performance variable was created by taking factorial scores related to the first axis. The variable was continuous and normally distributed and can thus be used as a dependent variable in a linear mixed model.

2.2.2. *Cognitive stimulation*

2.2.2.1. Cognitive stimulation at work. Information on cognitive stimulation at work was available for all participants when the first measurement was taken in 1996. Seven items (rated 0 or 1, with 1 indicating a positive answer) were used to assess cognitive stimulation at work. A principal component analysis was conducted on these items on the basis of a tetrachoric correlation matrix as variables were dichotomous. The first factor, which accounted for 34.3% of the total variance, was a size factor. It suggested the uni-dimensional nature of the latent cognitive-stimulation variable resulting from the seven items. The second factor accounted for 16.5% of the variance and revealed the following three sub-dimensions: (i) training opportunities, including one item indicating whether participants had received any occupational training during the past 5 years; (ii) qualifying aspects of the job, with three items referring to the cognitive richness of the work content and to whether the job allowed the worker to increase his/her abilities: 'my job enables me to learn new things', 'my job is varied', 'my job provides opportunities for me to increase my skill in the years to come'; (iii) cognitive effort, with three items reflecting a more intensive aspect of the work: 'having to hold a lot of information in my memory at once', 'having to do several things at once', 'having to face frequent interruptions while working'. The 62-year-old workers who were already retired in 1996 (83%, $n = 359$; years since retirement: mean 3.2, SD 2.5) were instructed to say whether these cognitive characteristics applied to their last job. As internal consistency was good (Cronbach's $\alpha = 0.71$), a score of cognitive stimulation at work (SAW) was computed by summing the ratings of the seven items (range: 0–7, with 7 indicating maximal cognitive stimulation at work).

2.2.2.2. Cognitive stimulation outside work. Information about cultural activities outside work was also assessed at baseline through two items: (i) reading; (ii) active participation in other cultural and artistic activities (e.g. music, painting, cinema). Items were rated 0 or 1, with 1 indicating a higher frequency of participation in these activities. A score of cognitive stimulation outside work (SOW) was obtained by summing the ratings of the two items (range 0–2, with 2 indicating the highest stimulation outside work).

2.2.2.3. General cognitive stimulation. In order to also examine in some analyses the joint effects of cognitive SAW and SOW, a score of general cognitive stimulation (STIMGEN) was created by summing the two. However, in order not to give SAW more weight than SOW, a weighted sum was calculated by having SOW rescaled from 0–2 to 0–7 before being added to SAW. Thus, the new score of STIMGEN ranged between 0 and 14, with 14 indicating the highest overall stimulation.

2.2.3. *Other variables studied*

Other variables studied were as follows:

(i) Time-related variables, which were the measurement occasion (1996, 2001 or 2006) and age at baseline.
(ii) Basic confounders were education (number of years) and sex.
(iii) A variety of information about the physical and mental status was also self-assessed and objectively recorded by the occupational physician according to a standardised protocol and were then controlled for in the analyses. Perceived health was obtained by getting the participants to give an overall evaluation of their state of health on a 10-point scale, ranging from 'very bad' to 'very good'. Information about mental stress was obtained through the short version of Cohen *et al.*' s (1983) perceived stress scale, with the total stress score ranging from 0 to 16 (maximum stress). As hypertension and obesity were found to be independently associated with lower cognitive scores (Elias *et al.* 2003), these variables were statistically controlled for. The current study used systolic blood pressure and BMI as continuous variables. BMI was calculated as weight (kg)/height $(m)^2$.
(iv) Physical, social and other cultural activities are aspects of engaged lifestyle, which have been shown to be positively associated with cognitive functioning and the rate of cognitive change (e.g. Seeman *et al.* 2001, Richards *et al.* 2003). In order to assess the specific effect of occupational experiences independently of these potential lifestyle influences, participants' physical and social activities at baseline were controlled for. Physically active sports and social activities (e.g. involvement in clubs, associations, organisations, local committees) were assessed separately by getting the participant to rate his/her participation in these activities on a 4-point Likert scale (0 = not at all, 3 = a lot). The variables were then dichotomised on the basis of the median; thus, distinguishing workers reporting lower (0) and higher (1) participation.

2.3. *Statistical analyses*

Linear mixed models were used to analyse the data in this study (Verbeke and Molenberghs 2000). Statistical analyses were performed using SAS/STAT® software version 9.2 of the SAS System for Windows. The mixed model expands on the ordinary linear regression model, in that it is compatible with a lack of independence between observations and also allows more than one error term to be modelled. The advantage of the linear mixed model over traditional analytic approaches to longitudinal data is that it models the covariance matrix. Thus, the fixed parameter estimates are more efficient and the model is more powerful in terms of testing the effects associated with the repeated measures, which is the core issue addressed in the current paper. This approach is also more reliable than traditional univariate and multivariate tests. Mixed models are more powerful, because they minimise the consequences of missing data. Attrition is very common in longitudinal studies. In the VISAT study, out of the 3123 participants seen at t1, 29.1% could not be seen again at t2 and 59.2% at t3. In traditional models, an observation corresponds to one participant and includes all available data about this participant, whereas in the mixed model an observation corresponds to the data concerning one participant on one measurement occasion. One major advantage of the mixed model over the traditional model is that when one participant is absent for one measurement date, only the observation relating to this occasion is ignored in the analysis, whereas in the traditional model, all data concerning the participant are ignored. The participants who did not show up on the second or third measurement occasion can be included in the analyses, thus limiting data waste and substantially increasing the power of the analyses.

Another frequently observed phenomenon in longitudinal studies is the regression to the mean. Due to random measurement errors (Barnett *et al.* 2005), repeated measures of the same variable between two groups will tend to be closer at the second measurement, whereas it logically should not if no action was performed between the two occasions. This phenomenon then tends to mask a tendency (Bland and Altman 1994) and has to be either measured or corrected. As, by definition, the effect of the regression to the mean is related to the measurement error of the first measurement occasion, a correction (Rocconi and Ethington 2009) has been applied to the baseline measurement of the general cognitive performance to reduce this effect. The following formula was used:

$$x_{corrected} = x - (1 - r_{xx})(x - \mu), \qquad (2)$$

where $x_{corrected}$ represents the corrected measurement value, x is the baseline value, r_{xx} the test–retest reliability and μ is the mean for the total sample. This formula uses the test–retest reliability and is adequate for multiple measurements at baseline. As in the present study multiple measurements were not available at baseline for all cognitive tests, an intraclass correlation coefficient was computed from the three successive learning/recall trials as an approximation of the test–retest reliability. Thus, this correction could be used to reduce the range of the measurements at baseline. Consequently, the potential regression to the mean effect has been reduced and should not be an issue in the results. Each analysis in the present paper has been computed with the corrected score.

3. Results

Because some individuals were lost or because of missing data, it was not possible to test all participants initially included in the study again on the second and third measurement occasions. The dropouts (29.1% and 59.2% at t2 and t3, respectively) were a little older (age: mean 45.38, SD 10.25 years and mean 43.57, SD 10.07 years for the dropouts and participants, respectively; $p < 0.0001$) and less educated (years of education: mean 11.51, SD 3.58 and mean11.87, SD 3.55, respectively; $p < 0.01$) than the individuals who participated on all three occasions. In order to examine the possible effects of an attrition bias, analyses were performed to compare dropouts and participants in terms of cognitive stimulation and cognitive performance at baseline. They revealed no significant difference in the score of cognitive stimulation at work (SAW: mean 3.87, SD 1.98 and mean 3.90, SD 2.00 for the dropouts and participants, respectively; $p = 0.69$). The same analyses were performed for STIMGEN and resulted in a similar outcome (STIMGEN: mean 6.70, SD 3.75 and mean 6.67, SD 3.70 for the dropouts and participants, respectively; $p = 0.83$). After adjustment for age and education, dropouts and participants showed a similar general cognitive performance at baseline ($p = 0.13$). These results suggest that biases due to t2- and t3-survivors differing from the initial sample in either cognitive stimulation or cognitive ability are probably minimised in the current study.

Analyses (linear mixed models) were then conducted to examine the effect of cognitive stimulation, with cognitive performance (factorial score) as a dependent variable. The first step consisted of computing two models, where the main effects of the selected variables were examined. In the first model, cognitive SAW (quantitative score 0–7) and cognitive SOW (quantitative score 0–2) were entered separately as continuous variables. In the second model, STIMGEN was used as a quantitative score, which incorporated both types of stimulation in a single score. Other variables were also entered in both models: measurement occasion (three levels), sex (two levels), physically active sports (two levels) and social activities (two levels) as factors; age at baseline, years of education, perceived health, perceived stress, systolic blood pressure and BMI as continuous variables.

In the second step, the same analyses were then conducted: (i) after removing perceived health, perceived stress, physically active sports and BMI, because they did not show any significant effect on the dependent variable in any of the two step-1 models; (ii) after interactions were introduced in the model. To consider all possible interactions in this second step would make no sense and would result in arduous interpretations. The present study thus focused on those interactions that are relevant for the hypotheses. These interactions were SAW × measurement occasion, SAW × age and SAW × measurement occasion × age, in models where SAW and SOW were analysed as separate predictors. In models where STIMGEN was used, these interactions were STIMGEN × measurement occasion, STIMGEN × age and STIMGEN × measurement occasion × age. In addition, quadratic effects of age were entered as a single effect and with the same interactions described for age to test whether a global quadratic effect of age could be found. Two models were thus calculated. These are displayed in Table 2, with Fisher's statistics, parameter estimates and t statistics associated with each estimate. Table 2 and subsequent Figures 1 and 2 show adjusted data. However, the reader who wishes to see raw (not adjusted) data can find them for the effects of age, of SAW and of STIMGEN as a function of measurement occasion in Appendices 1, 2 and 3, respectively.

The first model concerned SAW and SOW examined as separate predictors and included all variables and selected interactions that were significant (test *F*). Each quadratic effect of age was successively rejected because of non-significance, thus indicating a linear relationship between age and cognitive performance. The next model concerned STIMGEN as a general cognitive stimulation score, including only variables and interactions that were significant (test *F*). The same result was found for the quadratic effects of age as in the SAW and SOW models. As both models showed normally distributed residuals with homogenous variance, they were considered valid. Goodness-of-fit statistics are given at the bottom of the table: –2 times the logarithm of the likelihood, Akaike's information criterion, Akaike's information corrected criterion and the Schwarz Bayesian information criterion. The smaller they are, the better

Table 2. Predictors of cognitive performance.

Variables (reference category in parentheses)	SAW & SOW			STIMGEN		
	F	Estimate	T	F	Estimate	T
Sex						
Men	100.04**	–	–	92.32**	–	–
Women	–	0.5708	10.00**	–	0.5417	9.61**
Social activity						
No	14.34**	–	–	14.24**	–	–
Yes	–	0.2080	3.79**	–	0.2076	3.77**
Education	607.61**	0.2148	24.65**	643.17**	0.2190	25.36**
Systolic blood pressure	14.85**	−0.00744	−3.85**	16.39**	−0.00782	−4.05**
Measurement occasion (1996)	106.82**	–	–	113.73**	–	–
2001	–	1.7491	11.47**	–	1.7766	11.77**
2006	–	2.3611	12.72**	–	2.4142	13.19**
Age at baseline (years)	482.02**	−0.03432	−11.23**	477.57**	−0.03409	−11.14**
SAW	72.31**	0.07498	4.70**			
SOW	21.09**	0.1692	4.59**			
STIMGEN				92.68**	0.05271	6.05**
Measurement occasion × age (1996)	121.53**	–	–	121.64**	–	–
2001	–	−0.03425	−11.36**	–	−0.03419	−11.33**
2006	–	−0.05266	−14.11**	–	−0.05278	−14.14**
Measurement occasion × SAW (1996)	16.18**	–	–			
2001	–	0.05909	3.89**			
2006	–	0.09937	5.30**			
Measurement occasion × STIMGEN (1996)				14.45**	–	–
2001	–			–	0.02998	3.67**
2006	–			–	0.05088	5.00**
−2 log likelihood	23274.2			23268.4		
AIC	23278.2			23272.4		
AICC	23278.2			23272.4		
BIC	23290.3			23284.5		

SAW = stimulation at work; SOW = stimulation outside work; STIMGEN = general cognitive stimulation; AIC = Akaike's information criterion; AICC = Akaike's information corrected criterion; BIC = Schwarz Bayesian information criterion.

$*p \leq 0.05$; $**p \leq 0.01$.

Examples of how to read results displayed in the table are as follows. All other things being equal or held constant, the increase of 1 SD unit of SAW resulted in the increase of 0.07498 SD unit of the factorial score (see estimate in row 2 of model SAW & SOW for the SAW predictor).

Note: Results are for models where SAW and SOW were analysed separately or together using the STIMGEN variable.

the fit of the model. Parameter estimates give information about the direction of the effects.

An examination of the estimates of the SAW and SOW models reveals that cognitive performance increased significantly over the 10-year follow-up (measurement occasion). It also shows that a greater age at baseline and lower cognitive SAW and SOW were characteristics that were strongly associated with poorer cognitive performance. Estimated marginal means were used to interpret interactions in more detail. The interaction between age at baseline and measurement occasion was statistically significant. This interaction means that while cognitive performance increased with time since baseline (increasing positive values of the 2001 and 2006 estimates) and decreased with age at baseline (negative value of the age estimate), this decrease was stronger among older people over time (negative value of the interaction estimates). The other statistically significant interaction was the SAW × measurement occasion interaction. As shown in Figure 1, the pattern of cognitive change over the 10 years differed as a function of the level of cognitive SAW. This means that, regardless of the level of cognitive SOW, lower cognitive SAW was associated with a less pronounced improvement in performance over the first 5 years, and a decline in the subsequent 5-year period. This interpretation was confirmed by *post hoc* analyses. For several cognitive stimulation levels (SAW = 0, 2, 5, 7), t tests were performed to determine whether the mean cognitive performance differed significantly between two successive measurement dates. For people with the two highest tested levels of cognitive stimulation (SAW = 7 and 5), the t2–t1 difference was positive and statistically significant ($t = 11.27$, $p < 0.0001$ and $t = 14.83$, $p < 0.0001$, respectively), while the t3–t2 difference was not statistically significant ($t = 1.0$, $p = 0.32$ and $t = -0.21$, $p = 0.84$, respectively). For the groups with the two lowest tested

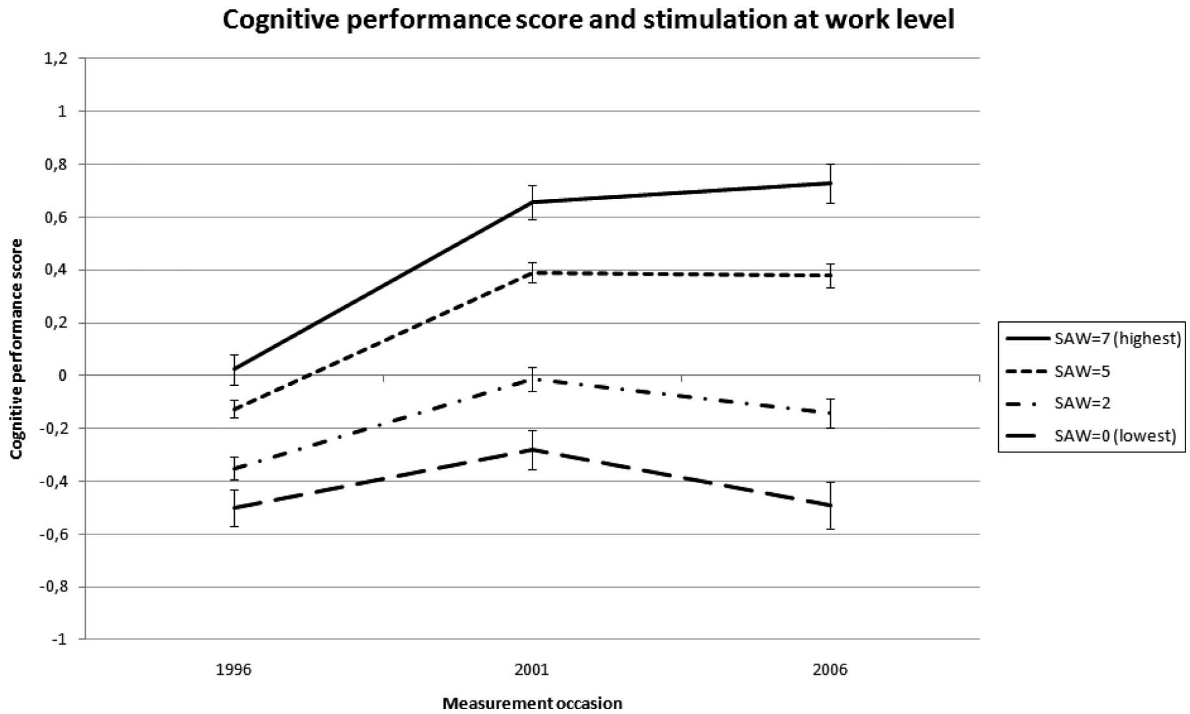

Figure 1. Mean (SE) score of cognitive performance as a function of cognitive stimulation at work (SAW: 0 = lowest, 7 = highest) and measurement occasion.

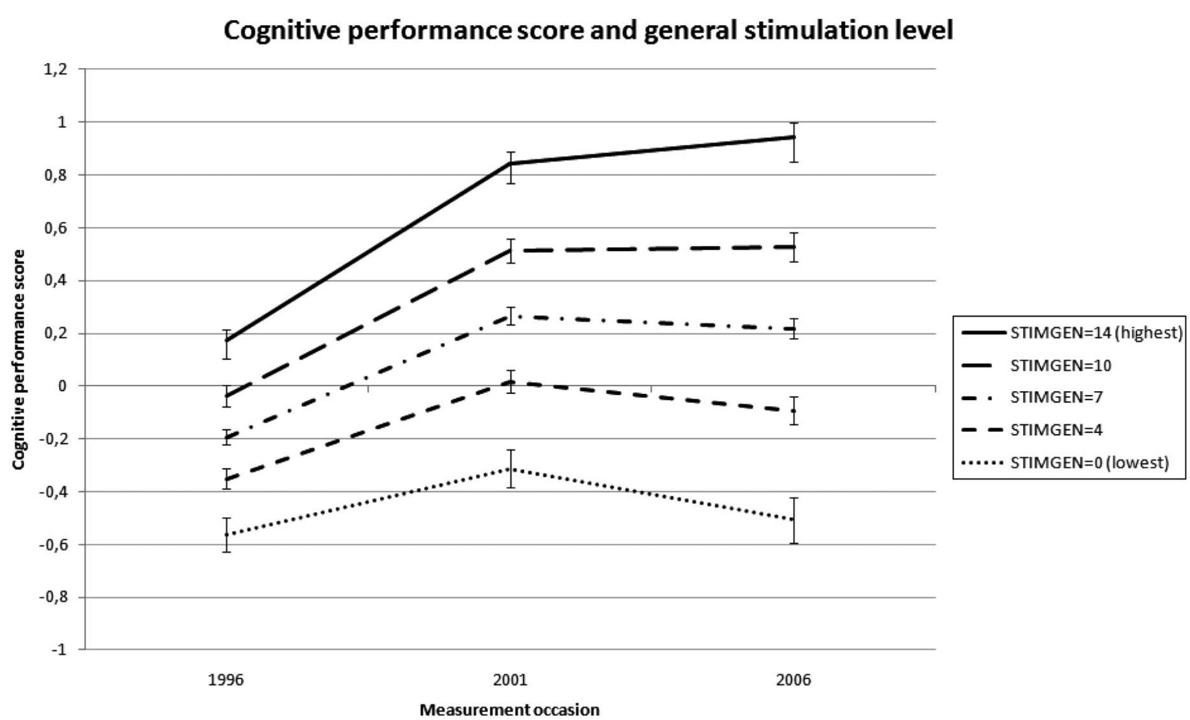

Figure 2. Mean (SE) score of cognitive performance as a function of general cognitive stimulation (STIMGEN: 0 = lowest, 14 = highest) and measurement occasion.

levels of cognitive stimulation (SAW = 0 and 2), the t2–t1 difference was also positive and statistically significant ($t = 3.30$, $p = 0.010$ and $t = 8.09$, $p < 0.001$, respectively) but the t3–t2 difference was negative and statistically significant ($t = -2.49$, $p = 0.0126$ and $t = -2.44$, $p = 0.0146$, respectively).

An examination of STIMGEN model estimates, with STIMGEN as a quantitative predictor reflecting cognitive stimulation both at work and outside work, yielded very similar results as those obtained in the SAW and SOW models. As can be seen in Table 2, the same effects on cognitive performance were observed for measurement occasion and age at baseline. Statistical levels of significance were also very similar to those observed in the SAW and SOW models. For the STIMGEN variable, results showed a statistically significant positive effect, thus indicating higher cognitive performance in people in more stimulating cognitive environments, both occupational and non-occupational. As in the SAW and SOW models, a statistically significant negative age (baseline) × measurement occasion interaction was obtained, which reflected that the tendency of the cognitive performance to increase between t1 and t3 was attenuated among older people. The measurement occasion × STIMGEN interaction was also positive and statistically significant, indicating that the pattern of cognitive change over the two successive 5-year periods differed significantly as a function of general cognitive stimulation (see Figure 2). Here again the present study tested for several levels of stimulation (STIMGEN = 0, 4, 7, 10, 14), whether the mean cognitive performance was significantly different between t1 and t2 and between t2 and t3. All t2–t1 differences were positive and statistically significant, indicating an increase in cognitive performance during the first 5-year period ($t = -4.00$, $p < 0.001$, $t = -9.89$, $p < 0.001$, $t = -15.09$, $p < 0.001$, $t = -13.46$, $p < 0.001$, $t = -9.95$, $p < 0.001$, respectively). Between t2 and t3, people exhibiting the highest levels of stimulation (STIMGEN = 7, 10 and 14) did not show any t2–t3 difference ($t = 1.20$, $p = 0.2317$, $t = -0.31$, $p = 0.76$, $t = -1.16$, $p = 0.25$, respectively), while for the lowest levels of stimulation (STIMGEN 0 and 4), t2–t3 differences were negative and statistically significant ($t = -2.42$, $p = 0.0155$; $t = -2.29$, $p = 0.0221$, respectively). These results clearly indicate that while all participants improved their performance in the first 5 years, probably due to the predominance of test familiarisation over the ageing effect, the pattern differed in the second time period as a function of cognitive stimulation. Indeed, people reporting less stimulating occupational and non-occupational experiences exhibited a significant decline in their cognitive performance in the subsequent 5-year period, unlike people who reported the highest stimulation level, whose cognitive performance was stable over the same period.

4. Discussion

Mental stimulation received in the workplace appeared to be a strong predictor of cognitive functioning, as assessed by a composite measure of cognitive performance. There was also found to be a significant relationship between cognitive performance and cognitive SOW and a measure combining stimulation both at work and outside work. However, it cannot be determined from this outcome whether higher mental stimulation is the cause or the consequence of a higher level of cognitive functioning, as people initially exhibiting higher functioning are also more likely to be found in cognitively demanding jobs. One strategy to distinguish initial ability and the effect of exposure to stimulating environments is to follow up large groups of people for long periods of time and to examine whether similar cognitive changes over that period are associated with exposure to such critical environments. In the context of this strategy, which was used in the current study, the ultimate support for the hypothesis is an interaction between test occasion and stimulation. The interaction was observed with both stimulation configurations; namely, with SAW and STIMGEN. This means that the rate of change differed over the 10-year follow-up as a function of stimulation. The most interesting feature of the outcome was that the lowest levels of stimulation were associated with a decline in cognitive performance in the second phase of the study, while cognitive performance was stable during the same phase for people with the highest levels of stimulation. This pattern of change over the 10-year follow-up did not differ as a function of age, as shown by the lack of interaction between age at baseline, test date and stimulation. This work thus supports the view that exposure to jobs that are cognitively demanding, but that are also varied, offers training opportunities and allows the worker to learn new things and develop his/her occupational competence in the long term, increases a person's level of cognitive functioning and possibly attenuates any age-related decline.

The results are in line with those of Schooler *et al.* (1999), who found that mentally demanding work activities had beneficial effects on intellectual flexibility, as assessed by an interviewer. Their study is one of the most demonstrative about the influence of occupational cognitive characteristics on cognition. The present findings are also consistent with those obtained in other studies, such as the Bosma *et al.* (2003) study, which showed that people with mentally demanding jobs had a lower risk of developing cognitive impairment over a 3-year period (see also Potter *et al.* 2006, Andel *et al.* 2007, Finkel *et al.* 2009). The results of the current study thus provide further support for these findings, as well as for the findings of other studies, which, although not explicitly focusing on work influences, also suggest that: 'Individuals who engage in activities that make significant loads on their cognitive skills will show greater maintenance or improvement of their abilities than individuals who are exposed to less complex environments with minimal cognitive loads' (Hultsch *et al*. 1999, p. 246, see also Christensen and Mackinnon 1993, Schooler and Mulatu 2001, Crowe *et al*. 2003, Singh-Manoux *et al*. 2003).

Several measures of cognitive stimulation were used in the present work, with the aim of being able to analyse the effects of cognitive SAW separately from the effects of cognitive SOW. It could be argued that, theoretically, it does not matter in what context mental stimulation takes place and that the type and magnitude of stimulation and its impact on cognitive function are far more important. However, it makes sense to specifically address the effects of mental SAW, because doing so leads to specific measures in occupational settings. Demonstrating a link between mental SAW and better or worse cognitive ageing would stress the importance of improving job content and working conditions during the four decades of a person's working life. The measure of cognitive SAW used in the present study showed good psychometric properties. As in previous work, job complexity and richness of the occupational environment were defined through both the effortful and the creative dimensions of the job's mental demands (Schooler *et al*. 1999, Bosma *et al*. 2003, see also Frias and Schaie 2001). This was not inferred from job title codes or any other external source, but self-assessed by workers under the supervision of an occupational physician who knew them well.

In the current study, a composite measure of cognitive performance was used, which was created from several memory and speed-based tests that varied in level of difficulty. Using this composite measure maximises the chances of meeting important statistical assumptions (e.g. normality of distribution) and of avoiding risks such as floor and ceiling effects and other sources of measurement error likely to distort estimates of change (Wilson *et al*. 2002). On average, cognitive scores improved slightly over time from baseline to follow-up. This improvement is statistically but not clinically significant because it is widely attributable to increased familiarisation with the test situation at follow-up. This is a persistent methodological problem inherent to longitudinal studies, where participants are repeatedly assessed with the same tests (e.g. Zelinski *et al*. 1993, Rabbitt *et al*. 2004).

The study has a number of both strengths and limitations. One strength is the large size and variety of the sample. Covering the full range of educational levels and a wide diversity of jobs increased the likelihood of detecting any effect that might only exist below a certain level of cognitive ability (e.g. Christensen and Mackinnon 1993). The risk of erroneous conclusions was minimised due to the fact that the outcome was obtained after controlling for various possible confounders, such as sex, education level and variables reflecting socially, physically, and culturally engaged lifestyles, as well as physical and mental health.

One limitation of the study is that it is a prospective longitudinal study: it predicted changes over time from occupational characteristics assessed at a given time. It was not fully longitudinal because it did not establish covariations between changes over time in cognitive stimulation and cognitive efficiency. Nevertheless, the present study was carried out with workers who held stable jobs on the whole; thus, greatly minimising the risk of the cognitive characteristics of the workers' occupational environments as assessed in this study being representative of only a small part of their career. At baseline, 93% of them reported that their current job was the job they had done the longest and 96% did not change occupational status. Another limitation of the study is that because certain individuals were lost or because of missing data, it was not possible to test all participants initially included in the study again at t2 and t3. However, the lack of difference between participants and dropouts at baseline for cognitive stimulation and cognitive performance suggests a possible limitation of attrition bias in the present study, although it cannot be fully ruled out.

A third limitation of the study is that, although it is still fairly long for this type of study, the 10-year follow-up was still too short, especially when test familiarisation is taken into account. Further assessment of the long-term effects of occupational environments on cognitive ageing needs a longer follow-up period. However, the fact that the association between the cognitive richness of the work environment and cognitive function was independent of the worker's age in the current study means that this association exists whatever the age of the worker and persists after retirement, since 83% of the oldest group were already retired at baseline and 100% at follow-up. Finally, evidence in favour of the preserving effect of cognitive stimulation was not obtained from the interaction between age at baseline and stimulation. This can be explained by historical factors that may have masked the expected effects, either by increasing the negative slope of the curve (drawn as a function of increased age) of the more stimulated participants or by reducing the negative slope of the less stimulated participants. Early nutritional, health and cultural influences, which were not controlled for in the current study, could plausibly have affected cognitive resources more in the older generations than in the younger generations. However, it is not clear why such factors could have influenced cognition differently in the two stimulation groups, i.e. negatively for highly stimulated people and positively for the less stimulated.

Cognitive efficiency is an increasingly sought-after resource in this information society, both in work situations and outside work. Cognitive efficiency has also become an important component of the widely shared aspiration of successful ageing. Long-term harmful effects of non-cognitive aspects of the work environment have been shown on cognitive resources (e.g. Rouch *et al.* 2005). Understanding how cognitive aspects of the work environment also affects the level of cognitive functioning and its change over time is important to ensure satisfactory work activity up to the end of a person's working life and to create the most favourable conditions for successful ageing. Yet European statistics show that older workers report less frequent access to occupational training and fewer opportunities to learn new skills in their job (Molinié 2003). Note that these conditions were associated in the present study with unfavourable cognitive consequences (see also Wight *et al.* 2002).

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References

Aartsen, M.J., *et al.*, 2002. Activity in older adults: Cause or consequence of Cognitive functioning. A longitudinal study on everyday activities and cognitive performance in older adults. *Journal of Gerontology Series B, Psychological Sciences and Social Sciences*, 57, P153–P156.

Andel, R., *et al.*, 2007. Complexity of main lifetime occupation and cognition in advanced old age. *Journal of Aging and Health*, 19, 397–415.

Barnett, A.G., van der Pols, J.C., and Dobson, A.J., 2005. Regression to the mean: what it is and how to deal with it. *International Journal of Epidemiology*, 34, 215–220.

Bland, J.M. and Altman, D.G., 1994. Some examples of regression towards the mean. *British Medical Journal*, 309, 780.

Bosma, H., *et al.*, 2003. Mental work demands protect against cognitive impairment: MAAS prospective cohort study. *Experimental Aging Research*, 29, 33–45.

Christensen, H. and Mackinnon, A., 1993. The association between mental, social and physical activity and cognitive performance in young and old subjects. *Age and Ageing*, 22, 175–182.

Cohen, A., *et al.*, 2008. Reading daily predicts reduced mortality among men from a cohort of community-dwelling 70 years-olds. *Journal of Gerontology Series B-Psychological Sciences and Social Sciences*, 63, S73–S80.

Cohen, S., Kamarck, T., and Mermelstein, R., 1983. A global measure of perceived stress. *Journal of Health and Social Behavior*, 24, 385–396.

Crowe, M., *et al.*, 2003. Does participation in leisure activities lead to reduced risk of Alzeimer's disease? A prospective study of Swedish twins. *Journal of Gerontology: Psychological Sciences*, 58, 249–255.

Elias, M.F., *et al.*, 2003. Lower cognitive function in the presence of obesity and hypertension: the Framingham heart study. *International Journal of Obesity and Related Metabolic Disorders*, 27, 260–268.

Finkel, D., *et al.*, 2009. The role of occupational complexity in trajectories of cognitive aging before and after retirement. *Psychology and Aging*, 24, 563–573.

Frias, C.M. and Schaie, K.W., 2001. Perceived work environment and cognitive style. *Experimental Aging Research*, 27, 67–81.

Friedman, G., 1964. *Le travail en miettes [Work smashed to smithereens]*. Paris: Gallimard.

Fritsch, T., *et al.*, 2007. Cognitive functioning in healthy aging: the role of reserve and lifestyle factors early in life. *Gerontologist*, 47, 307–322.

Gold, D.P., *et al.*, 1995. Structural equation model of intellectual change and continuity and predictors of intelligence in older men. *Psychology and Aging*, 10, 294–303.

Goldspink, D.F., 2005. Ageing and activity: their effects on the functional reserve capacities of the heart and vascular smooth and skeletal muscles. *Ergonomics*, 48, 1334–1351.

Hultsch, D.F., *et al.*, 1999. Use it or lose it: engaged lifestyle as a buffer of cognitive decline in aging? *Psychology and Aging*, 14, 245–263.

Karp, A., *et al.*, 2006. Mental, physical and social components in leisure activities equally contribute to decreased dementia risk. *Dementia and Geriatric Cognitive Disorders*, 21, 65–73.

Kohn, M.L. and Schooler, C., 1978. The reciprocal effects of the substantive complexity of work and intellectual flexibility: A longitudinal assessment. *American Journal of Sociology*, 84, 24–52.

Kolb, B., *et al.*, 1998. Age, experience, and the changing brain. *Neuroscience and Biobehavioral Reviews*, 22, 143–159.

Kramer, A.F., *et al.*, 2005. Fitness, aging and neurocognitive function. *Neurobiology of Aging*, 26, 124–127.

Marquié, J.C., 1997. Vieillissement cognitif & expérience: l'hypothèse de la préservation [Cognitive ageing and experience: the maintenance hypothesis]. *Psychologie Française*, 42, 333–344.

Marquié, J.C., *et al.*, 2002. Aging, health and work: Overview and methodology of the VISAT Prospective Study. *Le Travail Humain*, 65, 243–260.

Molinié, A.F., 2003. *Âge et conditions de travail dans l'Union Européenne [Age and working conditions in the European Union]*. Dublin: European Foundation for the Improvement of Working and Living Conditions.

Newson, R.S. and Kemps, E.B., 2005. General lifestyle activities as a predictor of current cognition and cognitive change in older adults: A cross-sectional and longitudinal examination. *Journal of Gerontology: Psychological Sciences*, 60, 113–120.

Potter, G.G., *et al.*, 2006. Occupational characteristics and cognitive performance among elderly male twins. *Neurology*, 67, 1377–1382.

Rabbitt, P., *et al.*, 2004. Practice and drop-out effects during a 17-year longitudinal study of cognitive aging. *Journal of Gerontology: Psychological Sciences*, 59, 84–97.

Rey, A., 1964. *L'examen clinique en psychologie [The clinical examination in psychology]*. Paris: Presses Universitaires de France.

Richards, M., Hardy, R., and Wadsworth, E.J., 2003. Does active leisure protect cognition? Evidence from a national birth cohort. *Social Science & Medicine*, 56, 785–792.

Rocconi, L.M. and Ethington, C.A., 2009. Assessing longitudinal change: adjustment for regression to the mean effects. *Research in Higher Education*, 50, 368–376.

Rouch, I., *et al*., 2005. Shiftwork experience, age and cognitive performances. *Ergonomics*, 48, 1282–1293.

Salthouse, T.A., 1991. *Theoretical perspectives on cognitive aging*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Salthouse, T.A., 1992. What do adult age differences in the Digit Symbol Substitution test reflect? *Journal of Gerontology*, 47, 121–128.

Salthouse, T.A., 2006. Mental exercise and mental aging: Evaluating the validity of the 'use it or lose it' hypothesis. *Perspectives on Psychological Science*, 1, 68–87.

Salthouse, T.A., Berish, D.E., and Miles, J.D., 2002. The role of cognitive stimulation on the relations between age and cognitive functioning. *Psychology and Aging*, 17, 548–557.

Schaie, K.W. and Abeles, R.P., 2008. *Social structures and aging individuals*. New York: Springer Publishing Co.

Schooler, C. and Mulatu, S.M., 2001. The reciprocal effects of leisure time activities and intellectual functioning in older people: a longitudinal analysis. *Psychology and Aging*, 16, 483–506.

Schooler, C., Mulatu, M.S., and Oates, G., 1999. The continuing effects of substantively complex work on the intellectual functioning of older workers. *Psychology and Aging*, 14, 483–506.

Seeman, T., *et al*., 2001. Social relationships, social support and patterns of cognitive aging in healthy, high-functioning older adults: MacArthur studies of successful aging. *Health Psychology*, 20, 243–255.

Singh-Manoux, A., Richards, M., and Marmot, M., 2003. Leisure activities and cognitive function in middle age: evidence from the Whitehall II study. *Journal of Epidemiology and Community Health*, 57, 907–913.

Sternberg, S., 1975. Memory scanning: new findings and current controversies. *Quarterly Journal of Experimental Psychology*, 27, 1–32.

Swaab, D.F., 1991. Brain aging and Alzheimer's disease: 'wear and tear' versus 'use it or lose it'. *Neurobiology of Aging*, 12, 317–324.

van Dijk, K.R.A., *et al*., 2008. No protective effects of education during normal cognitive aging: Results from the 6 year follow-up of the Maastricht Aging Study. *Psychology and Aging*, 23, 119–130.

Verbeke, G. and Molenberghs, G., 2000. *Linear mixed models for longitudinal data*. New-York: Springer Verlag.

Wechsler, D., 1955. *Wechsler Adult Intelligence Scale Manual*. New York: Psychological Corporation.

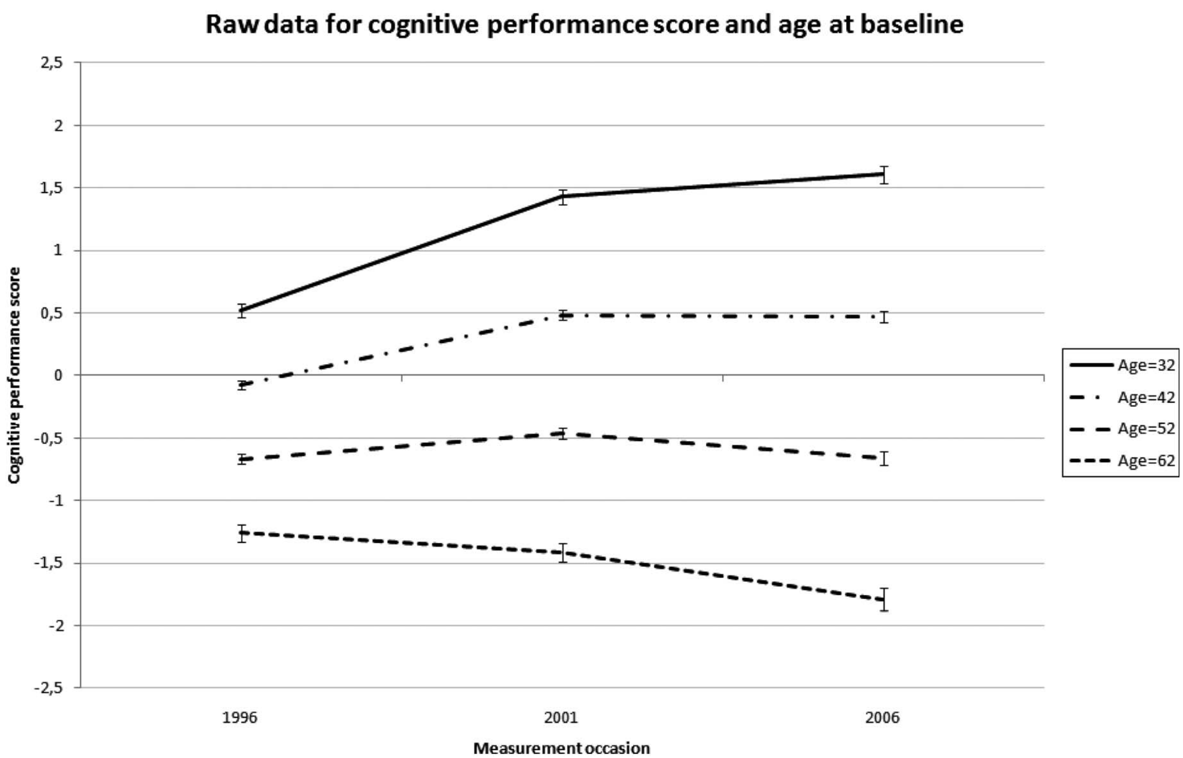
Wight, R.G., Aneshensel, C.S., and Seeman, T.E., 2002. Educational attainment, continued learning experience, and cognitive function among older men. *Journal of Aging and Health*, 14, 211–236.

Wilson, R.S., *et al*., 2002. Individual differences in rates of change in cognitive abilities of older persons. *Psychology and Aging*, 2, 179–193.

Yaffe, K., *et al*., 2009. Predictors of maintaining cognitive function in older adults: The Health ABC Study. *Neurology*, 72, 2029–2035.

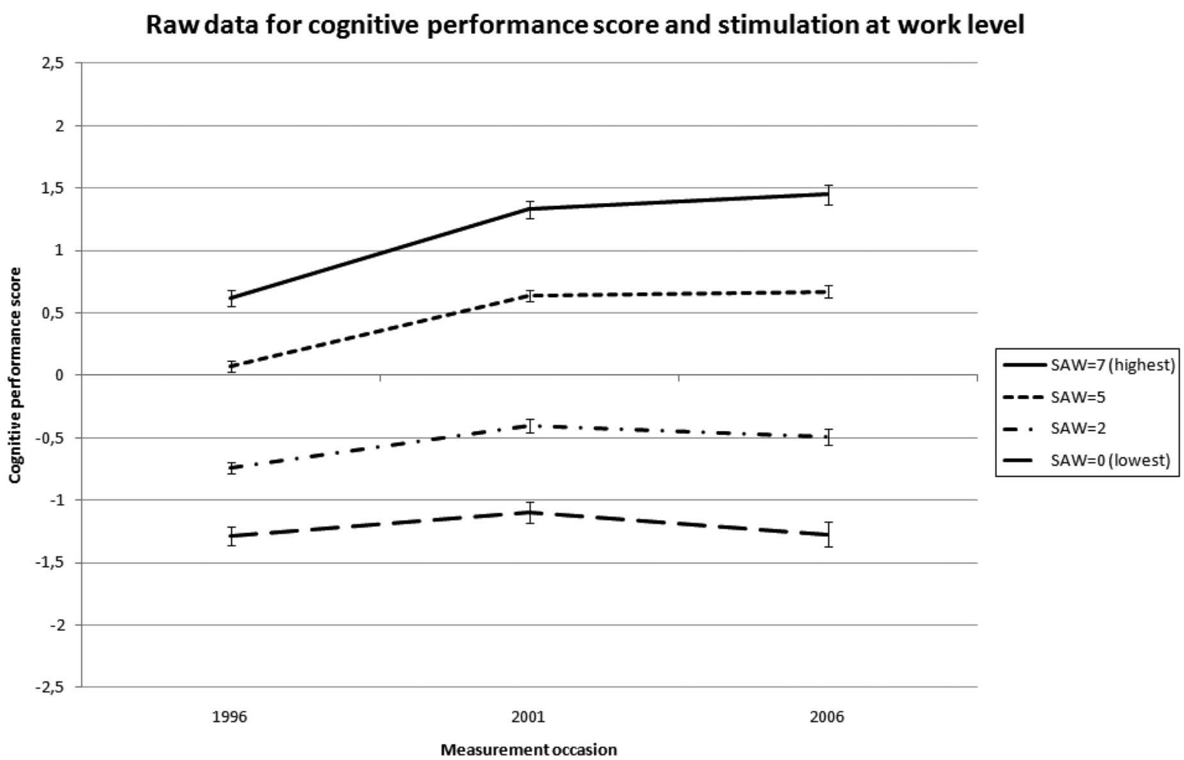
Zelinski, E.M., Gilewski, M.J., and Schaie, K.W., 1993. Individual differences in cross-section and 3-year longitudinal memory performance across the adult life span. *Psychology and Aging*, 8, 176–186.

Appendix 1: Raw data for cognitive performance (mean ± SE) as a function of age at baseline (32, 42, 52, 62 years) and measurement occasion



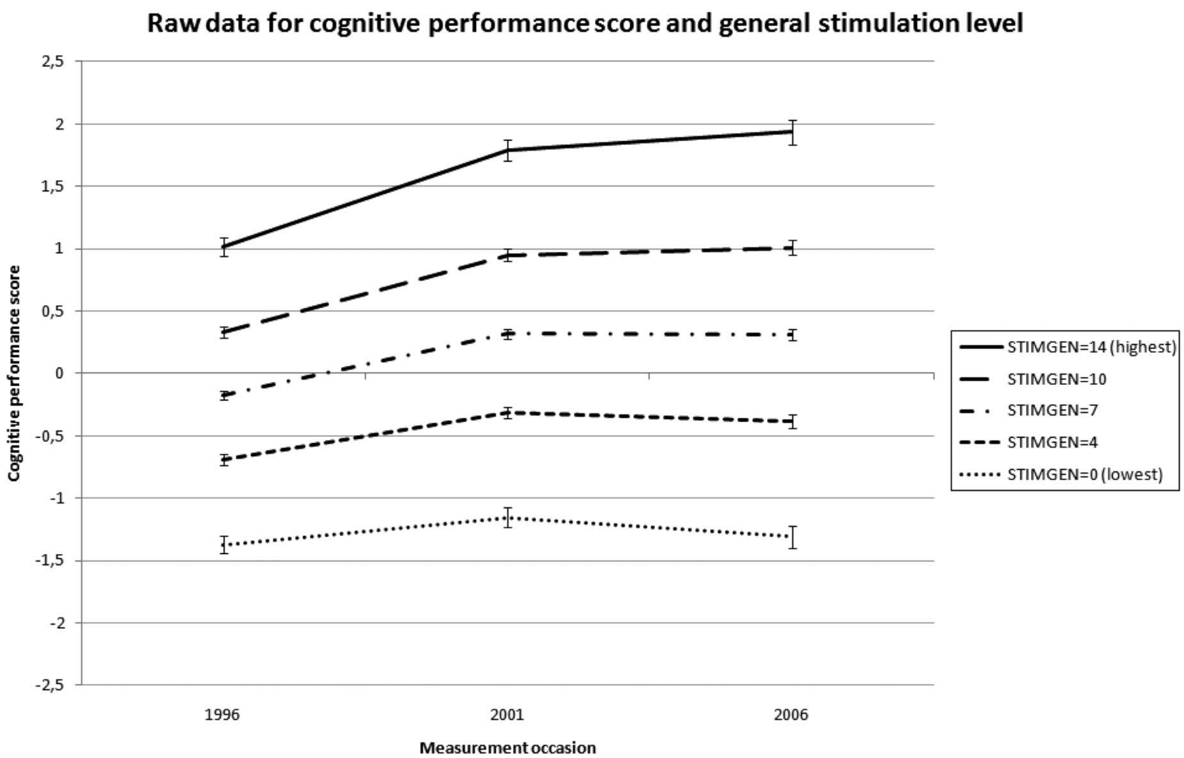
Note: These raw scores include the correction for regression to the mean.

Appendix 2: Raw data for cognitive performance (mean ± SE) as a function of cognitive stimulation at work (SAW: 0 = lowest, 7 = highest) and measurement occasion



Note: These raw scores include the correction for regression to the mean.

Appendix 3: Raw data for cognitive performance (mean $\pm$ SE) as a function of general cognitive stimulation (STIMGEN: 0 = lowest, 14 = highest) and measurement occasion.



Note: These raw scores include the correction for regression to the mean.