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COGNITIVE PERFORMANCE IN MIDDLE-AGED ADULTS AS A FUNCTION OF TIME OF DAY AND TASK LOAD

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Summary

The aim of this study was to explore the influence of task complexity and time of day on middle-aged shift-workers. Two groups of twelve subjects participated to this experiment: one Junior group (aged 20-30) and one Senior group (aged 50-60). Performance was assessed in two tasks involving different cognitive load: a simple visual discrimination task and a complex mental arithmetic test. The former was considered as an immediate processing task requiring little memory and attention, whereas the latter required a high mental load in working memory and attention. The subjects were tested in both tasks at three different times of the day simulating the main shifts: morning, evening and night. In each task, the test session lasted 60 minutes, divided into two 30-minute periods separated by a 20-minute rest. The results showed slower mental processing in both tasks in Seniors revealed by increased reaction time. Accuracy was also decreased, but only in the complex arithmetic test with an increase in error rate which was not observed in the simple perceptual task. Mental speed in the calculation task was decreased in both groups during the night session, but there was no time-of-day effect in the simple task. The time course of accuracy during the second period of the night session showed increased errors in Juniors but a decreasing trend in Seniors. Altogether, these results demonstrate that performance deficits due to age appear rather early in the lifespan, particularly when tasks involve high memory and attention load. However, the opposite profiles between Seniors and Juniors on accuracy during the night suggest a possible difference in strategies between young and old subjects which could help Seniors to partly counteract their deficits due to age.

Key Words: Human, Aging, Cognitive performance, Time-on-task, Time of day, Task complexity.

Introduction

During the past two decades, many studies explored the effects of shift-work on performance, accident rates and health. Thus, for example, it has been shown that night workers have not only reduced performance during their night-time activities (Folkard and Monk, 1979), but also higher accident rates compared with day workers (Akerstedt, 1995; Monk, 2000). Considering the health problems due to shift-work, sleep and gastrointestinal disorders as well as negative incidence on cardiovascular diseases have been reported (Costa, 1996).

Moreover, several recent studies have shown age-related alterations of the circadian timing system that might contribute strongly to the difficulties of adjustment to night work in elderly workers (Hofman, 2000; Van Someren, 2000). For instance, aging has been correlated to misalignment of phase relationship, amplitude decrease, difficulty of entrainment, increased "morningness" and a phase advance of the general activity rhythm (Akerstedt and Torsvall, 1981; Härmä et al. 1994; Dijk et al. 2000). Overall, such effects could result in general occupational health problems. For example, the new economical changes and constraints of the so-called 24-hour society, profoundly changed the timing of work and tend to generalize the resort to shift-work (Härmä and Ilmarinen, 1999), while the number of older shift-workers is growing in most developed countries due to the general aging of the working population (Ilmarinen and Costa, 2000). Many studies have been devoted to elderly persons, around 70 or more, but very little is known about middle-aged workers. These persons still cannot be considered as elderly, but they might already experience some deficits in work ability, while they have to face the same constraints than their younger counterparts.

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Finally, whatever the age, shift-work also raises the problem of the time-of-day effect on cognitive performance. A few authors have pointed out that performance quality is often related to task demand and more particularly with the short-term memory component of the task. Thus, performance on tasks with a high memory load show a continuous decrease throughout the day, whereas performance on more immediate processing tasks (such as simple serial search tasks) with little memory load show a continuous rise during the day, except perhaps for the transient post-lunch dip (Blake, 1967; Baddeley et al., 1970; Folkard, 1975). Folkard et al. (1976) have shown that performance on a high memory load task was negatively correlated with body temperature, thus achieving the maximal score during the night when temperature reached its minimum level (4h-6h), by contrast with immediate processing tasks where performance closely paralleled body temperature, reaching a peak at about 20h.

Consequently, it was demonstrated that complex tasks (such as verbal reasoning or mental arithmetic) involving both short-term memory and immediate processing showed an intermediate peak at about 14h, between the peak of short-term memory and that of immediate processing (Folkard et al., 1976; Folkard, 1990).

The aim of the present study was to compare performance in two different age groups of shift-workers (Juniors and Seniors) engaged in cognitive tasks characterised by high or low attention and memory load. The Senior group was chosen to belong to a middle-aged population, while the Junior group served as a control. Tasks were performed at different times of day reproducing common shift-work activity periods.

Our hypothesis was that performance deficits due to age may appear very early in the lifespan, so that even middle-aged people as compared to Juniors could possibly show impaired performance already due to deficits in attention and memory. This should be particularly true when the task is highly demanding on attention and memory load, but much less when it requires only immediate processing with little memory load. It was also investigated whether age was, or was not sensitive to time-of-day effects in relation to task demand.

Methods

Subjects.
Twenty-four subjects (23 females and 1 male) volunteered in this study. All of them were shift-workers (nurses) with a similar educational background.

Two groups of 12 subjects each were constituted. The first group (Control group) included young subjects (ranging from 20 to 30; mean age = 27.75 ± 2.55). It was called the Junior group. The second group (Experimental group) included middle-aged subjects (ranging from 50 to 60; mean age = 53.82 ± 2.43). It was called the Senior group. All subjects underwent a medical examination and had normal or corrected-to-normal vision, no sleep, medical or psychiatric disorders. They were informed about the general nature of the experiment and gave their informed consent.

The subjects were selected on the basis of the Horne and Ostberg morningness - eveningness questionnaire (Horne and Ostberg, 1976). Eighteen subjects were "intermediate" types, three "rather morning", two "rather evening", and one "definitely evening" type.

Material.
The experiment was conducted in two experimental chambers (one per subject) isolated from external light and noise, with constant ambient temperature (22°C) and hygrometry. Subjects underwent two tasks separated by a rest period during which they stayed in a common room adjacent to the chambers.

The stimuli were presented on a black-and-white monitor. They were generated through a PII Celeron computer coupled to a graphic card (VGA ATI) with a resolution of 640 x 480 pixels at a 60-Hz frame rate (not interlaced). Careful calibration of each red-green-blue combination was realized with an Optical version 1.2 photometer (Cambridge Research System). The video graphic adaptor constrained the minimal presentation duration of our stimuli (in the discrimination task) to about 16.7 ms, which is the time of one frame.

Procedure.
All the subjects underwent a training session two weeks before the experiment. They were trained to two tasks: a visual discrimination task and a mental arithmetic task (described below). Each task was performed during one hour. Therefore, subjects performed 1440 trials in the visual discrimination task, and between 600 and 800 trials depending on their speed in the mental arithmetic task. Whatever the task, subjects were excluded if there was more than 25 % error rate.

During the experiment, three different sessions simulating the main shifts were conducted: one morning session where subjects performed the tasks between 09:00 and 12:00, one evening session where subjects performed the tasks between 17:00 and 20:00, and one night session where subjects performed the tasks between 01:00 and 04:00. Each session was conducted with a one-week interval in a counterbalanced manner. Before the test sessions, subjects were asked to stay in the chamber for 10 min in order to get habituated to the dim light (0.09 lux) necessary to conduct the discrimination task.

The subjects performed each task during one hour divided into two periods of 30 minutes, separated by a rest period of 20 minutes to avoid excessive fatigue. Tasks were performed in a counterbalanced order in each age group. Thus, half of the subjects performed first the Visual Discrimination Task and then the Descending Subtraction Test, whereas the other half performed them in the reversed order. Between the two tasks, the subjects had an inter-task rest period of 20 minutes. On the whole, each session was going on as follows: 30 minutes on Task 1 - 20 minutes rest - 30 minutes on Task 1 / 20 minutes inter-task rest period / 30 minutes on Task 2 - 20 minutes rest - 30 minutes on Task 2, leading to a total of about three hours per session.

Visual discrimination task.
This task has been previously used in an experiment designed to assess circadian fluctuations of visual discriminability. It showed a high sensitivity to time-of-day effects (Tassi et al., 2000a) and for this reason, it has been used in the present study. This task is a typical immediate processing task with little demand in memory and attention. Subjects were sitting at 70 cm distance from the computer screen. They were asked to focus a central fixation dot (1.5 'arc diameter, 10 cd/m^2) during the inter-trial interval. After an auditory warning signal (1000 Hz, 500 msec), two stimuli appeared (i.e. white rectangles of 30 x 7.5 'arc of different luminance levels) either on the left or on the right of the central fixation dot. Subjects had to determine as fast and as accurately as possible where was the brightest stimulus by pressing either the left or the right arrow on the keyboard. To avoid anticipatory responses, five different preparatory periods (450, 550, 650, 750, and 850 msec) were used for the warning signal and presented randomly.

The stimuli appeared on a dark background with their centres located at 1.25° to the left and to the right of the fixation dot. Presentation time was about 83 msec. Nine different luminance intensities were used, according to the results obtained by Tassi et al. (2000). The luminance levels ranged into the photopic area linearly from 1.878 to 3.339 cd/m^2. At each trial, a standard stimulus appeared either on the left or on the right of the central fixation dot, while on the opposite side, one out of nine comparison stimuli appeared. Four luminance intensities were lower, one was equal, and four were brighter than the standard stimulus. The different luminance levels were randomly presented during an experimental session so that each level was presented 80 times, leading to a total of 720 trials per 30 min period. Each period was itself divided by the computer program into three 10 min blocks in order to analyse the time-course of performance throughout the test session. The dependent measures were reaction time and % error.

Descending Subtraction Test (DST).
The subjects sitting in front of the computer were asked to subtract successively descending digits from 10 to 1, starting from a three-digit number randomly generated by the computer. At each trial they typed their response on the digit keyboard and validated by pressing "Enter". Example: the computer generated the number 986. The subjects had to subtract 10 (976), then 9 (967), then 8 (959), etc… Arriving at 1, they carried on with 10, and so on. As soon as the subtraction cycle reached an amount inferior to 100, the program automatically generated a new three-digit number and the subjects were instructed to continue the mental operation with this new digit as if no change had occurred.

This task was high demanding in attention and memory load, as the subjects had to compute the mental subtractions and in the mean time keep in mind the last digit being subtracted. The task was self-paced so that the subjects could adopt the speed of mental calculation they decided. However, subjects were told to perform the task as fast and as accurately as possible. The dependent variables were the total number of response (whether right or wrong) as a measure of speed of mental processing, and the % error (wrong operations) as a measure of accuracy.

Physiological recordings.
Sublingual temperature was recorded during the inter-task rest-period during each session, using an electronic thermometer (Craftemp ET 2545).

Subjects were told to wear an actimeter during a period of 3 days preceding each experimental session, in order to control their sleep-wake cycle. Two of them were not authorized to wear it at their working place for safety reasons. Therefore, they were asked to provide written chronological details of their work-rest activities. All the subjects were asked to have normal sleep during at least 3 nights preceding each laboratory session, and were not allowed to sleep before the night session.

Subjective assessment.
After each test session and each rest period (except the rest period between Task 1 and Task 2), a questionnaire on subjective alertness, performance evaluation and estimated test duration was completed by the subjects. It was a visual analog scale of 1000 mm going from "Very sleepy" to "Very alert" for the item concerning Alertness. Performance was rated from "Very bad" to "Very good", and task duration from "Very short" to "Very long". Subjects put a mark on the level of the 1000 mm bar corresponding to their judgment. The number of millimeters from the left was then measured.

Statistical analysis.
The analyses were performed using a 2 x 3 x 2 x 3 ANOVA for repeated measures, with one between-subject variable (Age) and three within-subject variables (Time-of-day: morning/evening/night; 30 min test periods: P1/P2; 10-min blocks: B1/B2/B3 within P1 and B1/B2/B3 within P2). The computer program split the 30-min periods into 3 blocks of 10 minutes in order to measure the time course during each test session.

Post-hoc comparisons were conducted using the Newman-Keuls test (NK).

Results

Visual discrimination task.
The analysis of variance shows a significant Age effect on reaction time (F(1,16) = 5.33; p = 0.035) with increased reaction time in the Senior group (Figure 1). Whatever the group and the time of day, there is also a significant Period effect, (F(1,16) = 15.84; p = 0.001) with decreased reaction time after the rest period in the second part of the test session. However, there is no main time-of-day effect on reaction time (F(2,32) = 0.72; ns) and no difference between the 10 min blocks whatever the conditions (F(2,32) = 0.39; ns).

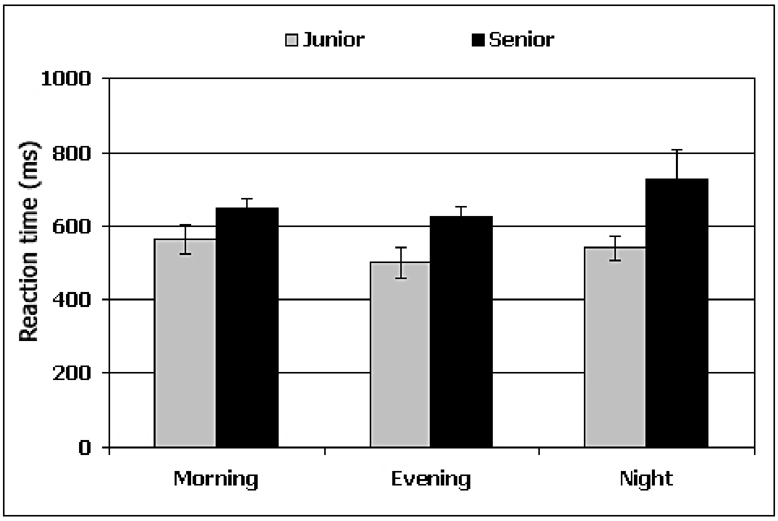

Figure 1. Mean reaction time in msec (± sem) in the Visual Discrimination Task during the morning, evening and night session in Juniors and in Seniors.

There is no Age effect on percent error (F(1,16) = 0.07; ns), and only a slight trend towards an increase in error rate during the night in both groups (F(2,32) = 2.86; p = 0.07). There is no difference on accuracy between the first and the second 30 min test session (F(1,16) = 0.49; ns). However, the ANOVA reveals a significant Block effect (F(2,32 = 6.56; p = 0.004) due to a of progressive increase in error rate from Block 1 to Block 3 in both periods, more obvious during the second period of the night session in the Junior group (Figure 2).

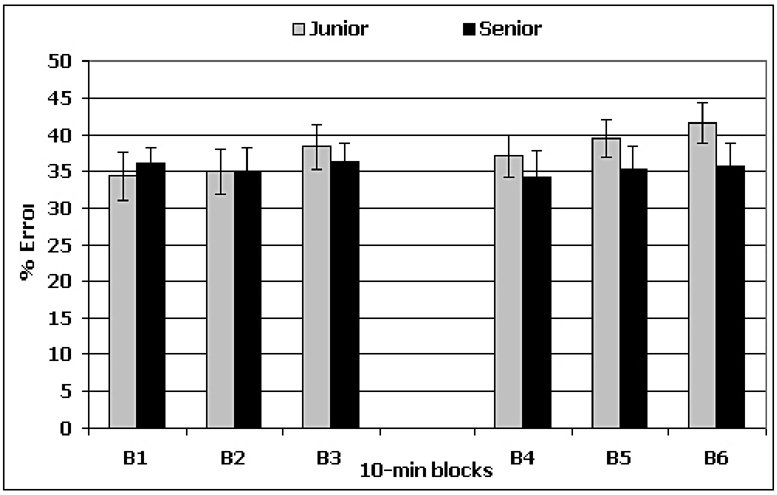

Figure 2. Time course of the mean percent error (± sem) by 10 min blocks in the Visual Discrimination Task during the night session in Juniors and in Seniors.

Descending Subtraction Test.
One subject has been excluded in the Senior group because of abnormal responses throughout the test. The analysis of variance shows an important Age effect on mean number of response (F(1,15) = 17.31; p = 0.0008) suggesting that, whatever the time of day, Seniors process significantly less mental operations than Juniors (Figure 3). There is also a significant time-of-day effect (F(2,30) = 4.42; p = 0.02) on speed. The post-hoc comparisons show increased response rate during the evening session

compared to the night (NK : p = 0.01), the morning session being intermediate with no statistical difference with the two others. The rest period produces an improvement on speed during the second period compared to the first (F(1,15) = 15.29; p = 0.001) present in the morning and in the evening session but not during the night.

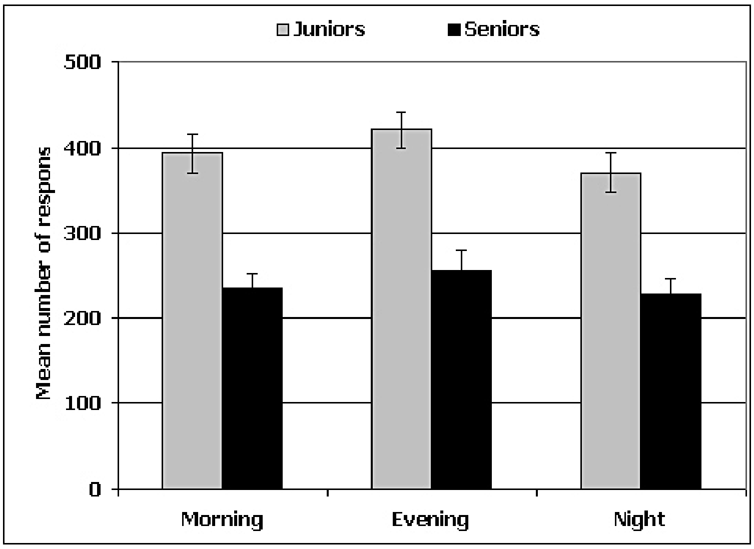

Figure 3. Mean number of response (± sem) in the Descending Subtraction Test during the morning, evening and night session in Juniors and in Seniors.

The ANOVA shows a significant Age effect (F(1,15) = 6.10; p = 0.02) with increased errors in Seniors compared to Juniors (Figure 4). There is no Time-of-day effect on error rate (F(2,30) = 1.37; ns) and no Period effect (F(1,15) = 0.12; ns) but a significant Age x Period interaction (F(1,15) = 6.45; p = 0.02) due to increased error rate in Juniors during the second test period compared to Seniors more obvious during the night session. This is strengthened by a significant Age x Block interaction (F(2,30) = 5.07; p = 0.01) showing a progressive increase of percent error during the second 30 min period in Juniors during the morning session but mainly during the night session, while Seniors display a progressive decrease in errors at the same time (Figure 5).

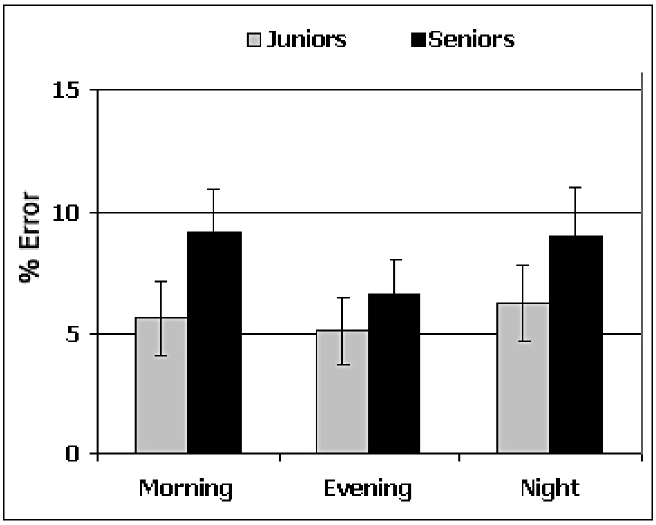

Figure 4. Mean percent errors (± sem) in the Descending Subtraction Test during the morning, evening and night session in Juniors and in Seniors.

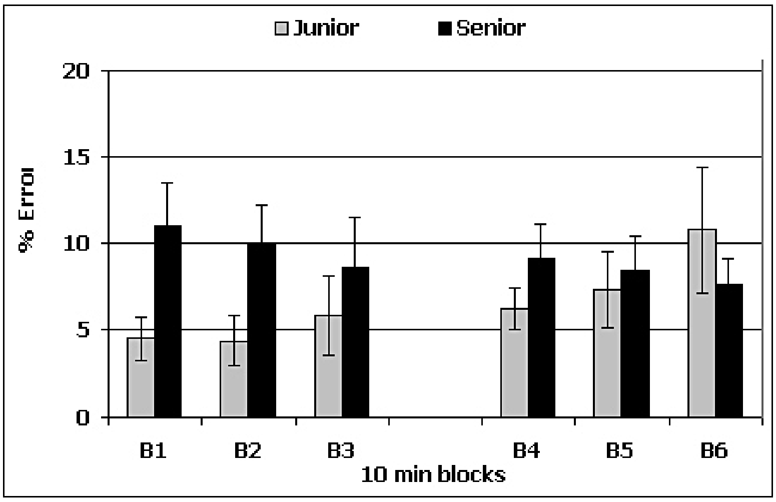

Figure 5. Time course of the mean percent error (± sem) by 10 min blocks in the Descending Subtraction Test during the night session in Juniors and in Seniors.

Subjective questionnaire.
The visual analog scale has been presented to the subjects after both tasks in order to compare the general feeling of alertness, self-rating of performance and of task duration in the Visual Discrimination Task and the Descending Subtraction Test.

The results show no Age effect on alertness whatever the task but a significant Time-of-day effect. In the Visual Discrimination Task (F(2,40) = 12.87; $p < 0.0001$), alertness was lower during the night session (NK : morning vs night : p = 0.0002; evening vs night : p = 0.0003). The same was observed in the Descending Subtraction Test (F(2,40) = 7.94; p = 0.001). Post-hoc comparisons showed a significant difference between the morning and the night session (NK : p = 0.003) and between the evening and the night session (NK : p = 0.001).

Self-rating of performance showed a significant Age effect in the Descending Subtraction Test (F(1,20) = 12.24; p = 0.002) with lower ratings in Seniors compared to Juniors, which corresponds to the objective performance. But there is no difference between age groups in the Visual Discrimination Task (F(1,20) = 0.05; ns). In both groups, self-rating of performance are significantly decreased during the night session as compared to the morning and evening sessions, as suggested by a significant Time-of-day effect in the Visual Discrimination Task (F(2,40) = 10.31; p = 0.0002. NK respectively : p = 0.0004 and p = 0.001) and in the Descending Subtraction Test (F(2,40) = 3.86; p = 0.02. NK respectively : p = 0.02 and p = 0.05).

Task duration is rated as longer by Juniors compared to Seniors in the Visual Discrimination Task, as suggested by a significant Age effect (F(1,20) = 4.69; p = 0.04) but not in the Descending Subtraction Test. Whatever the age and the task, there is no Time-of-day effect on subjective task duration.

Physiological recordings.
The ANOVA reveals an important Time-of-day effect in sub-lingual temperature (F(2,40) = 6.93; p = 0.002). Post-hoc comparisons show that this difference is due to a decrease in temperature during the night in both age groups (NK : Morning vs Night : p = 0.01; Evening vs Night : p = 0.002). There is also a significant difference between both age groups with lower temperature whatever the time of day in Seniors compared to Juniors (F(1,20) = 4.41; p = 0.04).

Discussion

The results of this experiment show a significant impairment in the Senior group compared with the Junior group in both speed and accuracy in the Descending Subtraction Test, and in speed (but not in accuracy) in the Visual Discrimination Task. These data suggest that even in a middle-aged population of 50 to 60 years old, attention and memory resources are decreased in an important manner.

The Descending Subtraction Test is high demanding in attention and memory load since it requires to store many information in working memory in order to process mental operations. Therefore, it is also sensitive to attentional lapses as attention is necessary to process this information. This is why it has been extensively used in sleep deprivation (Stampi et al. 1990) as well as in hypovigilance paradigms (Mullington and Broughton, 1994) because of its sensitivity to alterations of attentional resources. It has been shown that age deficits are probably more related to storage capacity than to processing deficit (Foos, 1989). This age-associated decline in explicit or declarative memory is thought to be due to changes in the functioning of neural systems that support memory processes (Light, 1991; Stebbins et al. 2002). It could explain why, in our experimental conditions, the senior subjects showed impaired performance in the Descending Subtraction Test both on speed of processing and on accuracy.

By contrast, the Visual Discrimination Task is very simple and considered as an immediate processing task, with almost no demand in memory and attentional resources. There is no visual categorization nor recognition since the stimuli are simple rectangles without any semantic component and therefore this task, by contrast with the Descending Subtraction Test, implies very early perceptual processes and probably no memory at all.

In this task, only speed of processing was affected by age but not accuracy. It is well known that reaction time is usually the first variable influenced by age and many studies on aging have shown increased reaction time in older people in complex as well as in simple tasks (Wickens et al. 1987; Parasuraman et al. 1989; Ratcliff et al. 2001). However, the absence of age effect on accuracy could be due to the fact that this task involves only early cognitive processes with no demand in attention and memory.

It could also be suggested that the impairment of performance in the Senior group is related to a difference in oral temperature, which was significantly lower in the Senior group whatever the time of day. The effect of internal temperature on performance, and specifically in simple tasks, has been extensively demonstrated, in particular when it is associated with partial sleep deprivation (Tassi et al. 2000b).

The results concerning the effect of time of day show that during the night session, there was a significant decrease in speed in the Descending Subtraction Test but not in the Visual Discrimination Task. This result is surprising since both groups rated their alertness as very low during the night session and this perceptual task appeared to be very sensitive to hypovigilance in a previous experiment conducted by Tassi et al. (2000a). The main difference between both studies concerns the subject sample. In the present study, subjects were all shift-workers used to work during the night time, whereas in Tassi et al. (2000a), participants were students unfamiliar with night work. However, mental operations were slower in the more complex task suggesting that, if training could help maintaining performance, it was true only up to a certain extent. For instance, accuracy was not decreased during the night in the Descending Subtraction Test, but showed a slight trend towards a decrement in the Visual Discrimination Task. It appears therefore, that depending on task complexity, speed and accuracy would not be influenced in the same way in adverse conditions like hypovigilance. In our conditions, in the complex task, accuracy was spared at the expense of speed, while the opposite pattern tend to occur in the simple perceptual task.

Age could be a factor interacting with these differences. The analysis of the time-course of performance by 10-min blocks showed that in both tasks Juniors and Seniors did not show the same profile in error rate during the night session. In the Descending Subtraction Test, percent error in Juniors increased progressively with time-on-task while the opposite pattern occurred in Seniors with a progressive decrease in error rate. Moreover, the rest period has always been beneficial on speed in both age groups, leading to a general improvement during the second 30 min period whatever the task. But this was not the case for accuracy leading to a significant Age x Period interaction due to an increase in error rate in the second part of the night session in Juniors but not in Seniors.

It is suggested that Seniors and Juniors may not apply the same strategies when performing a complex task in a state of hypovigilance. Seniors could privilege accuracy, hence leading to a more cautious attitude towards the task as compared to Juniors. This hypothesis is strengthened by higher scores in self-rating of performance in the complex task in Juniors, suggesting more self-confidence in this group than in Seniors whatever the time of day. Differential strategies between younger and older people have been suggested by several authors in different conditions (Miller and Stine-Morrow, 1998; Rogers et al. 2000; McEvoy et al. 2001; Crawford and Channon, 2002). In our experiment, time-on-task may be a critical factor to determine specific response strategies, mainly when it is associated with hypovigilance.

It could therefore be of interest to investigate other work-rest schedules in order to evaluate the effect of time-on-task, for instance without intermediate rest period, and to have a close look in these conditions, on possible strategies used by young and middle-aged healthy adults in order to better understand what are the main determinants of optimal working conditions in relation with work ability.

References

Akerstedt, T. Work hours, sleepiness and the underlying mechanisms. *Sleep Res.*, 1995, 4: 15-22.

Akerstedt, T. and Torsvall, L. Shiftwork. Shift-dependent well-being and individual differences. *Ergonomics*, 1981, 24: 265-273.

Baddeley, A. D., Hatter, J. E., Scott, D., Snashall, A. Memory and time of day. Quarterly *J. Exp. Psychol.*, 1970, 22: 605-609.

Blake, M. J. F. Time of day effects on performance in a range of tasks. *Psychon. Sc.*, 1967, 9: 349-350.

Costa, G. The impact of shift and night work on health. *Appl. Ergon.,* 1996, 27: 9-16.

Crawford, S. and Channon, S. Dissociation between performance on abstract tests of executive function and problem solving in real-life-type situations in normal aging. *Aging Ment. Health,* 2002, 6(1): 12-21.

Dijk, D.J., Duffy, J.F., Czeisler, C.A. Contribution of circadian physiology and sleep homeostasis to age-related changes in human sleep. *Chronobiol. Int.*, 2000, 17: 285-311.

Folkard, S. Circadian performance rhythms: some practical and theoretical implications. *Phil. Trans. Royal. Soc. Lond. Series B, Biological Sciences*, 1990, 327: 543-553.

Folkard, S. Diurnal variation in logical reasoning. *Br. J. Psychol.*, 1975, 66(1): 1-8.

Folkard, S., Knauth, P., Monk, T. H., Rutenfranz, J. The effect of memory load on the circadian variation in performance efficiency under a rapidly rotating shift system. *Ergonomics*, 1976, 19(4): 479-488.

Folkard, S., and Monk, T. H. Shiftwork and performance. *Human Factors*, 1979, 21: 483-492.

Foos, P.W. Adult age differences in working memory. *Psychol. Aging*, 1989, 4(3): 269-275.

Härmä, M.I. and Ilmarinen, J.E. Towards the 24-hour society - new approaches for aging shiftworkers. *Scand. J. Work, Environ. Health*, 1999, 25(6, special issue): 610-615.

Härmä, M.I., Hakola, T., Akerstedt, T., Laitinen, J.T. Age and adjustment to night work. *Occup. Environ. Med.*, 1994, 51: 568-573.

Hofman, M. The human circadian clock and aging. *Chronobiol. Int.*, 2000, 17: 245-259.

Horne, J. A. and Ostberg, O. A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *Int. J. Chronobiol.*, 1976, 10(2): 171-176.

Ilmarinen, J.E and Costa, G. Aging of the working population in the European Union. *Med. Lav.*, 2000, 91(4): 279-295.

Light, L.L. Memory and aging: four hypotheses in search of data. *Ann. Rev. Psychol.*, 1991, 42: 333-376.

McEvoy, L.K., Pellouchoud, E., Smith, M.E., Gevins, A. Neurophysiological signals of working memory in normal aging. *Brain Res. Cogn.*, 2001, 11(3): 363-376.

Miller, L.M. and Stine-Morrow, E.A. Aging and the effects of knowledge on on-line reading strategies. *J. Gerontol. B. Psychol. Sci. Soc. Sci.*, 1998, 53(4): 223-233.

Monk, T. H. What can the chronobiologist do to help the shift worker? *J. Biol. Rhythms.*, 2000, 15: 86-94.

Mullington, J. and Broughton, R. Daytime sleep inertia in narcolepsy-cataplexy. *Sleep*, 1994, 17: 69-76.

Parasuraman, R., Nestor, P., Greenwood, P. Sustained-attention capacity in young and older adults. *Psychol. Aging*, 1989, 4(3): 339-345.

Ratcliff, R., Thapar, A., McKoon, G. The effects of aging on reaction time in a signal detection task. *Psychol. Aging*, 2001, 16(2): 323-341.

Rogers, W.A., Hetzog, C., Fisk, A.D. An individual differences analysis of ability and strategy influences: age related differences in associative learning. *J. Exp. Psychol. Learning, Memory and Cognition*, 2000, 26(2): 359-394.

Stampi, C., Moffitt, A., Hoffman, R. Leonardo da Vinci's polyphasic ultrashort sleep: a strategy for sleep reduction. I. Sleep architecture. *Sleep Res.*, 1990, 19: 406.

Stebbins, G.T, Carrillo, M.C., Dorfman, J., Dirksen, C., Truner, D.A., Bennett, D.A., Wilson, R.S., Desmond, J.E., Glover, G. Aging effects on memory encoding in the frontal lobes. *Psychol. Aging*, 2002, 17(1): 44-55.

Tassi, P., Pellerin, N., Moessinger, M., Hoeft, A., Muzet, A. Visual resolution in humans fluctuates over the 24h period. *Chronobiol. Int.*, 2000a, 117(2): 187-195.

Tassi, P., Dufour, A., Dewasmes, G., Muzet, A. Effects of ambient temperature on signal detection in a paradigm of inverted sleep-wake cycle. *Eur. Rev. App. Psychol.*, 2000b, 49(4): 195-202.

Van Sommeren, E.J.W. Circadian and sleep disturbances in the elderly. *Exp. Gerontol.*, 2000, 35: 1229-1237.

Wickens, C.D., Braune, R., Stokes, A. Age differences in the speed and capacity of information processing: a dual-task approach. *Psychol. Aging*, 1987, 2(1): 70-78.

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