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Abstract

Cognitive procedural learning is characterized by three phases, each involving distinct processes. Considering the implication of the episodic memory in the first cognitive stage, the impairment of this memory system might be responsible for a slowing down of the cognitive procedural learning dynamics in the course of aging. Performances of massed cognitive procedural learning were evaluated in older and younger participants using the Tower of Toronto task. Nonverbal intelligence and psychomotor abilities were used to analyze procedural dynamics, while episodic memory and working memory were assessed to measure their respective contributions to learning strategies. This experiment showed that older participants did not spontaneously invoke episodic memory and presented a slowdown in the cognitive procedural learning associated with a late involvement of working memory. These findings suggest that the slowdown in the cognitive procedural learning may be linked with the implementation of different learning strategies less involving episodic memory in older subjects.

KEYWORDS: aging, episodic memory, cognitive procedural learning, procedural memory, Tower of Toronto task, working memory.

Procedural memory is defined as the memory system in charge of the encoding, storage and retrieval of procedures which underlie motor, verbal and cognitive skills. Procedural learning is the process whereby a procedure is encoded in procedural memory. Previous investigations of cognitive procedural learning have suggested that skills undergo three characteristic phases (cognitive, associative and autonomous) involving different cognitive processes in the course of the learning of complex procedures (ACT model; Adaptive Control of Thoughts; Anderson, 2000). According to the ACT model, learning a new cognitive procedure requires highly controlled processes in the initial cognitive phase and more automatic ones in the final autonomous phase. The boundaries of these procedural learning stages can notably be delimited using an experimental method (Ackerman and Cianciolo, 2000) consisting in analyzing the correlations' changes with practice between the procedural learning level and the cognitive determinants specific of each learning phase. We previously used the TT task to further categorize these three learning phases in younger adults, analyzing the cognitive determinants of procedural performance levels for each trial in the learning process (Beaunieux et al., 2006). Our findings confirmed the existence of two such determinants for the cognitive phase (nonverbal intellectual abilities) and autonomous phase (psychomotor abilities), which proved to be the best markers of their boundaries. They also helped us to improve our understanding of the roles played by the two memory systems, the episodic memory and the working memory, in the implementation of the learning strategies. Episodic memory is currently described as the memory system notably in charge of the encoding, storage and retrieval of personally experienced events, associated with a precise spatial and temporal context of encoding and a specific state of consciousness (Tulving, 2001). According to Baddeley (2000 and 2003), working memory is a memory system composed of both slave systems and a central executive considered as similar to the executive functions (Baddeley, 1996).

This cognitive theoretical framework of the procedural learning, fitting with neuroimaging data (Hubert et al., 2007), could be useful in explaining the different conclusions reached by studies on the effects of aging on cognitive procedural learning. Because of differences in performance levels, some studies have concluded that the learning of cognitive procedures is impaired in older subjects (Davis & Bernstein, 1992). Others, because of the absence of any effect of age on performance improvement, have concluded that cognitive procedural learning is preserved in normal aging. These latter studies have reported normal ability in elderly subjects to automate cognitive procedure such as solving the TH (Vakil & Agmon-Ashkenazi, 1997) or the TT task (Peretti, Danion, Gierski & Grange, 2002). Nevertheless these studies do not analyze cognitive procedural learning dynamics with direct reference to Ackerman's conceptions (1988, 1990). Only the study of Head et al. (2002) supports the idea, in accordance with Ackerman's (1988) conception, that in the course of aging, cognitive variables such as executive functions and working memory involved in the first stage of procedural learning, and particularly vulnerable to age (West, 1996), might be responsible to the effect of age on cognitive procedural learning. Nevertheless, this study only proposed a few learning trials. Only the first stages of the acquisition were examined, not investigating the autonomous one i.e. the encoding into procedural memory. Further investigations including a large number of trials seem to be required to study the effect of age on cognitive procedural dynamics, ie. the linking of the three learning phases. In the same way, the contribution of episodic memory in cognitive procedural learning difficulties in older subjects has to be defined. Baddeley and Wilson (1994) have stressed the major contribution of episodic memory in procedural learning. Recently, we showed the involvement of episodic memory in automation of the TT task in young subjects (Beaunieux et al., 2006). Owing to the well-established effect of age on episodic memory, it might be hypothesized that the dynamics of cognitive procedural learning would be disturbed.

Above and beyond the issue of the preservation or deterioration of procedural memory in healthy aging (based on indicators of improvements or performance levels respectively), we set out to use these two indicators to find out how and why aging may affect procedural learning abilities. We therefore decided to study cognitive procedural learning using a combined methodology issue from our two previous studies (Beaunieux et al., 2006; Hubert et al. 2007), in order to specify the effect of age on the dynamics of cognitive procedural learning and the implication of episodic memory in the phenomenon. The aims were (1) to study, in older subjects, the dynamics of cognitive procedural learning using the TT task, (2) to characterize the contributions of episodic memory and working memory during the acquisition of this cognitive procedure.

METHOD

Subjects

A total of 100 unpaid volunteers from two different age groups (50 younger and 50 older participants) were tested. The 50 young subjects were selected from the 100 of our previous study (Beaunieux et al., 2006), according to their vocabulary level (measured by the Mill Hill Scale; Deltour, 1998) in order to be matched to the 50 elderly subjects. A health questionnaire was used to screen all the subjects for any history of neurological or psychiatric conditions, head injury and alcohol or drug abuse. Two subjects were excluded for traumatic head injury and three for drug abuse. Because the procedural task involved the processing of colors, participants were also screened for color blindness using the Ishihara Test (Ishihara, 1997). Three subjects were excluded for color blindness. We made sure that none of the participants were familiar with the TT problem. We made sure that all subjects in the older sample did not show signs of neurodegenerative pathologies by examining that they performed within normal limits on the Mattis Dementia Rating Scale (MDRS). Five old subjects were excluded for a score without normal limits on the MDRS. The study was conducted in line with the Declaration of Helsinki.

The overall characteristics of the samples are reported in Table 1.

Insert Table 1 about here.

Materials

The experimental protocol featured two sessions separated by an interval of one week. The first session was taken up by the procedural learning of the TT task while subjects underwent a set of supplementary cognitive tasks in the second session.

1) Procedural task (TT task)

The TT task consisted of a rectangular base and three pegs. Four different-colored disks were used: one black, one red, one yellow and one white. The TT disks were initially stacked on the leftmost peg, with the darkest one at the bottom and the lightest one on top. The task consisted in rebuilding this configuration on the rightmost peg, obeying the following two rules: only one disk may be moved at a time, and a darker disk may never be placed on top of a lighter one. These rules were read out to the subjects and explained through examples of authorized and unauthorized moves. All the instructions were printed on a sheet of paper placed near the subject. Participants were asked just to solve the problem; no reference was made to completing it in the fewest possible moves or shortest possible time.

We also added a rule that provided a cue for the subjects: begin by putting the white disk on the middle peg. This instruction was given in order to avoid a probably random choice by the subjects. The TT device was connected to a computer, which recorded the completion time (in seconds) and the number of moves per trial for each subject. The minimum number of moves for the 4-disk TT task is 15. As we gave a clue for the first move, this move (and the time it took) was not taken into account. The optimum solution was thus 14 moves.

To enable them to reach the autonomous phase, the subjects performed 40 trials of the TT task (8 blocks of 5 consecutive trials, with a 5-minute break between each block). This number of trials is largely sufficient for younger subjects to reach the autonomous phase (Beaunieux et al., 2006) and, according to Peretti et al. (2002), may also be sufficient for older ones.

2) Cognitive tasks

As in the study by Beaunieux et al. (2006), we assessed nonverbal intelligence and psychomotor functions. *Nonverbal intellectual functions* were assessed using the Block Design subtest of the Wechsler Adult Intelligence Scale (WAIS-III; Wechsler, 2001, French version). In order to assess *psychomotor abilities*, we asked the subjects to carry out two disk transfer tasks. The aim was to transfer 4 disks (one by one) from the leftmost peg to the middle peg, then to the rightmost peg and finally back to the leftmost one. The only instruction we gave was to use only one hand. This transfer task was performed twice (before and after the procedural learning of the TT task). The same transfer task was performed with the Tower of London task.

We also measured the efficiency of episodic memory and working memory. E*pisodic memory* was assessed using an abridged form of the California Verbal Learning Test (CVLT) and pairing and free recall of the digit symbol-coding. During the CVLT, sixteen words were presented only once and subjects immediately had to recall them. Free recall of the digit symbol-coding consists in delayed recalling as many of the previously-seen symbols as possible. Lastly, *working memory* was assessed by means of span tests: the WAIS-III digit forward span (Wechsler, 2001) allowed us to evaluate the slave systems of working memory.

The ability to handle information in working memory was also measured, using the Letter Number Sequencing test taken from the WAIS-III.

Statistical analyses

Assessment of cognitive procedural learning

Performances of the 50 younger and 50 older subjects on the TT task were assessed by means of two variables: the number of moves and the total problem-solving time (in seconds) per trial. Aggregating the data by block would yield a more stable estimate of performance for each group and limit the number of subsequently calculated correlations. A multivariate analysis of variance (MANOVA) was carried out, with performances on the 4 blocks (of 10 trials) as the repeated measure and groups as a between-subjects factor. Complementary analyses on each session were conducted by mean of t-tests.

Effect of aging on supplementary cognitive tasks

For episodic memory and working memory we calculated a composite score corresponding to the sum of the scores collected with the tests evaluating each cognitive function (episodic memory composite score maximum = 43 and working memory composite score maximum = 30). In order to test the effect of age on the nonprocedural components, t-tests were therefore used to compare the younger and older groups for each composite score. Intellectual and psychomotor raw scores were also compared by means of t-tests.

Delimitation of the three learning phases of the TT task for each group

The three learning phases were determined in a three-stage analysis carried out separately for each group. As in the first stage of the statistical analyzes of Hubert et al. (2007), the delimitation of the three learning phases was done for each individual subject, using the number of moves per trial. The length of the cognitive phase therefore corresponded to the number of trials during which the subject failed to find the optimum solution. The length of the associative phase corresponded to the number of trials during which the subject solved the procedure in 14 moves or near this optimum solution. Lastly, the length of the autonomous phase corresponded to the number of trials during which the subject solved the procedure in 14 moves.

In the same way as Beaunieux et al. (2006), the second stage consisted of correlations between the intelligence and psychomotor scores on the one hand and performances in terms of total time per block of the TT task on the other hand. We chose not to consider the number of moves here, as it was not sufficiently sensitive - this variable loses its variability once the subjects have found the solution to the problem and thus does not fully reflect the automation of the cognitive procedure.

In the third and last stage, we compared the correlations with intelligence with those with psychomotor abilities (calculated for each block) by means of Steiger's Z* statistic (Steiger 1980) which tests for the differences in each of the two correlation matrix. Our aim was thus to delimit the three phases for the older group in order to compare them with those of the younger group.

For the two groups, we expected a greater contribution of nonverbal intellectual abilities than psychomotor abilities during the cognitive phase and the opposite results during the autonomous phase, the associative phase being characterized by no significant difference between the two cognitive determinants.

Effect of age on the dynamics of cognitive procedural learning

In order to study the effect of age on the dynamics of cognitive procedural learning we first compared the average length of the each three phases in the two groups by means of t-tests.

We then compared the involvement of the intelligence and psychomotor abilities in cognitive procedural learning in the two groups by applying Fisher's test (1921). First, we assessed the age-related differences in correlations between nonverbal intellectual abilities and procedural learning performances (total time per block). The differences for each block were expressed as z scores. The same analysis was carried out for the correlations between psychomotor abilities and performances (total time per block). A contribution of nonverbal intellectual abilities or psychomotor abilities statistically more significant in the younger group than in the older one will result in z score > 1.65 whereas Z score < - 1.65 will translate the opposite result.

In consideration of the effect of age on cognitive procedural levels in aging, we expected that the cognitive and associative phases would be longer for the older group.

Characterizing the procedural learning phases for each group

Lastly, in order to study the contributions of episodic memory and working memory during cognitive procedural learning, we examined the correlations between the episodic and working memory composite scores and procedural learning performance (total time per block) for each group. We also compared the involvement of these components in the two groups by applying Fisher's test (1921).

We expected a differential involvement of episodic and working memory in the two groups.

RESULTS

Assessment of cognitive procedural learning

Regarding the time taken to solve the TT task, the MANOVA showed a significant group effect (F (1,98)=33.5; p<.0001), a significant block repetition effect (F(3,294)= 223.7; p<.0001) and a significant interaction between block and group (F(3,294)=12.6; p<.0001; Figure 1A). T-tests conducted for each block showed that there was a significant difference between the two groups on the four blocks (block 1: t(98) = 4.8, p <.0001; block 2: t(98) = 4.9, p <.0001; block 3: t(98) = 5.3, p<.0001 and block 4: t(98) = 4.1, p<.0001).

In terms of the number of moves, to the MANOVA revealed a significant effect of group ($F(1,98) = 18.9$; $p<.0001$), a significant block repetition effect ($F(3,294) = 94.6$; $p<.0001$) and a significant interaction between the two effects ($F(3,294) = 2.9$; $p<.03$; Figure 1B). T-tests conducted for each block showed that there was a significant difference between the two groups on the four blocks (block 1: $t(98) = 3.1$, $p = .003$; block 2: $t(98) = 3.3$, $p =.0015$; block 3: $t(98) = 4.9$, $p<.0001$ and block 4: $t(98) = 4.6$, $p<.0001$).

Insert Figure 1 about here

Effect of aging on supplementary cognitive tasks

The comparison of the mean cognitive scores of the younger and the older groups are show in Table 2. Results did not reveal significant effect of age on non-verbal intelligence abilities but showed a significant deleterious effect of age on psychomotor abilities, episodic memory and working memory.

Insert Table 2 about here

Delimitation of the three learning phases for each group

<u>Length of the learning phases (Hubert et al. 2007)</u>

Table 3 reports the length of the three learning phases in the two groups. Broadly speaking, the cognitive phase of the younger group covered trials 1-4, the associative phase trials 5-18, and the autonomous phase trials 19-40. The cognitive phase of the older group covered trials 1-13, the associative phase trials 14-33 and the autonomous phase trials 34-40.

Insert Table 3 about here

<u>Correlational analyses (Beaunieux et al. 2006)</u>

In the younger group, nonverbal intelligence was significantly correlated with procedural performance levels in the first half of the learning process, during the blocks 1 and 2. Psychomotor abilities were significantly correlated with procedural performance levels from the 2nd block onwards (Figure 2A). The comparison of the two sets of correlations (nonverbal intellectual abilities and psychomotor abilities) revealed that there was no significant difference in favor of the involvement of intellectual capacities. During the blocks 3 and 4, there was a significant difference in favor of psychomotor abilities ($t(37) = -3.5$, $p = .0013$ and $t(37) = -5.2$, $p < .0001$ respectively).

In the older group, nonverbal intelligence abilities were significantly correlated with procedural performance levels during the blocks 1, 2 and 4, while psychomotor abilities were significantly correlated with procedural performance levels from during the blocks 3 and 4, i.e. one block later than for the younger group (Figure 2B). The comparison of the two sets of correlations showed that there were no significant overall differences but a tendency for the block 1 ($t(37) = 1.5$, $p = .13$), revealing a greater contribution of intellectual abilities. Contrary to the younger subjects there were no significant differences in favor of the psychomotor abilities.

Insert Figure 2 about here

Effect of age on the dynamics of cognitive procedural learning

Comparison of the mean length of the learning phases in the two groups showed that the cognitive and the associative phases of the older subjects were significantly longer than in the younger group whereas the autonomous phase was significantly shorter (Table 3).

Using Fisher's test, the analyses revealed that the involvement of intellectual abilities in performances did not differ significantly between the two groups but tented to be significant ($p<.06$) in favor of the older group in the block 4 (Figure 2C). By contrast, the correlations with the psychomotor abilities were significantly stronger for the younger group than for the older during the blocks 3 and 4.

Characterizing the procedural learning phases for each group

The correlations between episodic and working memory and procedural performances indicated that episodic memory was significantly correlated with performance levels only in the first half of the learning process and only in the younger group (Figure 3A). We did not observe any significant correlations between episodic memory and procedural performance levels for the older group.

In the younger group, working memory was not significantly correlated with learning performance but seemed to be more involved at the beginning of the learning process and gradually decreased thereafter (Figure 3B). In the older group, working memory was significantly correlated to the performance levels only in the block 4.

Fisher's test showed only that the correlations with episodic memory were significantly superior in the younger group than in the older one in the block 1 (Figure 3C). Regarding working memory, there were statistical tendencies for the two last blocks in favor of a greater involvement in older group than in the younger ones.

Insert Figure 3 about here

DISCUSSION

The results of the present investigation confirm first of all the beneficial effect of trial repetition on performance both in terms of time and number of moves required to solve the TT task in younger and older subjects. However, the significant interaction indicated that because the additional time and moves necessary to solve the TT task in the older subjects, they had to improve their performance with practice more than the younger ones. Post hoc comparisons showed that older subjects did not catch up the younger performance levels at the end of the learning. These results are consistent with those of Peretti et al. (2002) and

Vakil and Agmon-Ashkenazi (1997) who found older subjects were able to acquire the TT task procedure in spite of a deleterious effect of age on performance levels.

Comparison of the mean length of the learning phase in the two groups showed that the cognitive and the associative phase were significantly longer in the older group and that autonomous phase was therefore shorter, suggesting that the autonomous phase may be delayed for fifteen trials in the older subjects. These results confirm that despite their improvement, older subjects were slowed down in the cognitive procedural dynamics. More precisely, there may be a lengthening of the two first phases of the learning with age, deferring but not jeopardizing the autonomous phase.

In reference with Ackerman's (1988) model, we then studied the extent to which nonverbal intelligence and psychomotor functions determined procedural performance levels and confirmed the boundaries of the learning phases in both groups. The results of the 50 younger subjects were, as expected, similar to those reported by Beaunieux et al. (2006) in 100 subjects (including those 50), showing three distinct phases in cognitive procedural learning. Psychomotor abilities mainly determined procedural performance levels during the blocks 3 and 4, suggesting that these two last blocks may correspond to the autonomous phase. These data seem to fit perfectly with the boundaries defined by the first analysis (trials 19-40 i.e. blocks 3 and 4). The cognitive phase of the young subjects covered trials 1-4 but our results did not reveal a greater contribution of nonverbal intellectual abilities than psychomotor abilities in block 1. These findings might be accounted by the shortness of the cognitive phase in the younger: they were already in associative phase at the end of the first block and the aggregate of the data by block hampered us to conduct correlations strictly during the cognitive phase.

With regard to the older group, the first analysis suggested that the cognitive phase covered trials 1-13 (block 1), the associative phase trials 14-33 (block 2, 3 and 4) and the autonomous phase trials 34-40 (block 4). Correlational analysis showed that in the block 1, the differences between intellectual and psychomotor abilities tended to be significant, suggesting that this block may correspond to the cognitive phase in concordance with the first analysis. The associative phase, corresponding to the absence of any difference between the two determinants, may correspond to the last blocks (2 to 4) as it was suggested by the first analysis. The absence of greater involvement of the psychomotor abilities compared with the nonverbal intelligence in block 4 contradicts the predictions of Ackerman's model but may be explained by the same raisons as those mentioned for the younger subjects. Older subjects were still in the associative phase at the beginning of the last block and the aggregate of the data by block may mask the significant contribution of the psychomotor abilities at the end of the last block. We have to take these methodological limits into consideration and interpret these data with caution. Further studies with larger samples would allow correlational analysis "trial by trial" as it was done by Beaunieux et al. (2006) and therefore permit a more refined comparison between these two modes of analysis of the cognitive procedural dynamics.

The comparison of the two groups on the basis of the two main determinants of the learning process showed that the two groups differed solely regarding the psychomotor component, mainly during the blocks 3 and 4 in accordance with the comparison of the mean length of the learning phases. These differences, observed over two blocks, confirm the slowdown in the dynamics of cognitive procedural learning of the older subjects compared with the younger.

The characterization of the different learning phases highlighted the contribution of episodic memory in the younger group especially at the beginning of the learning process (Wilson, Baddeley, Evans & Shield, 1994), i.e. during the cognitive phase. On the contrary, our results suggest that the older subjects did not invoke episodic memory during the cognitive and the associative phase but rather working memory, suggesting therefore different learning strategies in the two groups. The slowdown in the learning abilities of the older subjects may be explained by the episodic memory alteration which hampers the procedural learning process by preventing an effective correction of the errors (Baddeley and Wilson, 1994). They seemed to solve the problem all along the learning blocks without trying to explicitly remember the strategies previously used. The automation of the procedure may be delayed because of these episodic difficulties in older participants who rely, maybe by compensation, on their working memory capacities. Thus, the use of different learning strategies, in the two groups may account for the slowdown in the cognitive procedural learning in the older, as it has already been described in alcoholic patients (Pitel et al., 2007). In contrast with our older subjects, alcoholic patients were characterized by a late involvement of both episodic and working memory. These results were also considered as reflecting compensatory mechanisms to generate the cognitive procedure in spite of episodic deficits. Further studies should permit to explore this compensatory role of working memory.

CONCLUSION

To conclude this experiment, our findings highlight the interest to analyze jointly improvement capacities with performance levels to examine the effect of age on cognitive procedural learning. Furthermore, the study of the cognitive determinants allows unraveling the fine grained differences in the processes underlying the automation of a cognitive procedure in normal aging and thus a better understanding of the various conclusions from literature. Our findings suggest that older subjects improve their procedural performances but at a worse level owing to a less involvement of episodic memory that delayed the automation of the cognitive procedure. The assessment of the strategies invoked by the two groups emphasizes the “optimizer” role of the episodic memory in cognitive procedural learning. In effect, in presence of episodic deficits, cognitive procedural learning is not impossible but slows down. It would be relevant to use such experimental methods to better understand the remaining procedural abilities in amnesic patients.

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Table 1: Characteristics and cognitive scores of the younger and older subjects

		Younger subjects (N=50)	Older subjects (N=50)	p value
Sex ratio (males/females)		26/24	22/28	
Age	Mean (SD)	22.2 (4.5)	67.5 (8.3)	.0001
	Range	18-34	55-95	
Vocabulary level (Mill Hill)	Mean (SD)	26.0 (2.7)	26.3 (4.8)	.72
Dementia rating (MDRS)	Mean (SD)	/	142.2 (1.8)	/

SD = Standard deviation; max. score of the Mill Hill=34; MDRS = Mattis Dementia Rating Scale, cutt-off score=138, max. score=144

Table 2: Cognitive scores of the younger and older subjects

Cognitive function	Task	Dependent variable	Max. score	Younger subjects (N=50) Mean (SD)	Older subjects (N=50) Mean (SD)	t	p value
Intelligence abilities	Block Design	Number of marks	20	10.7 (2.0)	10.9 (1.9)	0.5	.62
Psychomotor abilities	Disk transfer task	Average of the two transfer times	/	2.8 (0.5)	3.1 (0.5)	2.8	.007
Episodic memory	California Verbal Learning Test	Number of correctly recalled words	16	7.7 (2)	8.1 (2.4)	0.9	.36
	Digit symbol coding		27	23.7 (3.8)	14.8 (6)	-8.8	.0001
	Composite score*		**43**	**31.3 (4.8)**	**22.8 (7.3)**	**-6.9**	**.0001**
Working memory	Digit forward span	Maximum number of correctly recalled items	9	6.0 (0.1)	5.3 (0.1)	-4.3	.0001
	Letter Number sequencing test		21	12.6 (0.3)	10.1 (0.3)	-4.2	.0001
	Composite score*		**30**	**16.0 (1.9)**	**13.8 (1.6)**	**-6.1**	**.0001**

SD = Standard deviation; *: the composite scores (in dark) were used in all statistical analyses; degree of Freedom=98 for all the analyses

Table 3: Length of the three learning phases (number of trials) in the younger and older subjects

	Younger subjects (N=50) Mean (SD)	Older subjects (N=50) Mean (SD)	t	p value
Cognitive phase	4.1 (4.3)	13.1 (10.4)	5.2	< .001
Associative phase	13.9 (8.8)	19.7 (10.4)	2.8	.006
Autonomous phase	21.9 (11.1)	7 (9.5)	-7.2	< .001

SD = Standard deviation; degree of Freedom= 98 for all analyses

Figure captions

Figure 1: Performance trends in terms of completion time (A) and moves (B) per block during the four learning blocks in the tower of Toronto task.

The results show a significant learning effect across the 4 blocks, a significant group effect, and a significant interaction between learning and group.

Figure 2: Effect of age on the dynamics of cognitive procedural learning

A: Correlations between procedural performance levels (time in seconds) and the intelligence and psychomotor scores for the younger subjects.

The boldface horizontal line corresponds to the statistical threshold $p = .05$. The correlations located above this line are significant.

B: Correlations between procedural performance levels (time in seconds) and the intelligence and psychomotor scores for the older subjects.

The boldface horizontal line corresponds to the statistical threshold $p = .05$. The correlations located above this line are significant.

C:. Comparison of the inter-group determinants (correlations).

Calculated z-value, assessing the existence or otherwise of a significant difference between the two groups for the two determinants (intelligence and psychomotor abilities), calculated for each trial. The boldface horizontal lines correspond to the tabulated z-value $p = .05$. The calculated z-values located above or below these lines are significant. The difference is in favor of the younger subjects for $z > 1.65$ and in favor of the older ones for $z < -1.65$.

Figure 3: Correlations between procedural performance levels (time in seconds) and (A) episodic memory and (B) working memory scores in younger subjects and older subjects. (C): Calculated z-value, assessing the existence or otherwise of a significant difference between the two groups for these two components (episodic memory and working memory).

The boldface horizontal lines correspond to the statistical threshold $p = .05$. The correlations or the tabulated z-value located above these lines are significant.