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EXAMEN DES EFFETS DE L'ÂGE SUR L'APPRENTISSAGE DE SÉQUENCES SPATIALES SOUS DES CONDITIONS D'ENCODAGE INTENTIONNEL ET INCIDENT.

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Sommaire

Récemment, à partir de la tâche d'apprentissage spatial supra-empan de Hebb (Hebb, 1961), une étude de Turcotte, Gagnon et Poirier (2001) a démontré que les personnes âgées arrivent difficilement à faire l'acquisition de manière non-intentionnelle d'une séquence de positions spatiales. Dans cette tâche, le participant doit faire un rappel sériel immédiat de séquences de carrés présentées aléatoirement sur un moniteur. Tous les carrés sont présents à l'écran et s'illuminent les uns après les autres. À l'insu du participant, une séquence est répétée après la présentation de deux séquences aléatoires. L'apprentissage s'observe par l'augmentation graduelle du rappel sériel immédiat de la séquence répetée, tandis que le rappel sériel immédiat des séquences aléatoires reste relativement stable. Une des hypothèses pouvant expliquer l'effet d'âge observé par Turcotte et al. (2001) stipule que les jeunes adultes prendraient plus rapidement conscience de la séquence répétée que les personnes âgées et utiliseraient des stratégies explicites pour en faire l'encodage et la récupération. L'objectif principal de cette étude est de vérifier à quel point l'intention de mémoriser la séquence répétée peut avoir un effet sur l'apprentissage de celle-ci et conséquemment provoquer une différence entre les participants jeunes et les âgés. Cette question est d'autant plus pertinente puisque les effets du vieillissement en apprentissage de séquences semblent importants et persistants lorsqu'il y a récupération volontaire de la séquence répétée (p. ex. Arenberg & Robertson-Tchabo, 1977 ; Howard & Howard, 1989 ; 1992 ; 1997 ; Meulemans & Van der Linden, 1997). Pour ce faire, nous avons administré la version spatiale de la tâche d'apprentissage supra-empan de Hebb à 45 jeunes adultes âgés de 18 à 32 ans et à 47

personnes âgées ayant entre 66 et 80 ans. Dans cette tâche, vingt-cinq séquences d'une longueur correspondant à l'empan à laquelle on ajoute deux carrés ont été présentées. Les participants sont évalués sous l'une des deux conditions possibles. Dans la condition incidente, le participant n'est pas informé de la répétition d'une séquence. Dans la condition intentionnelle, le participant est informé de la répétition et du moment de son apparition. L'analyse des résultats indique, qu'en général, les jeunes adultes présentent un meilleur rappel que les personnes âgées en plus d'arborer un apprentissage significatif de la séquence répetée. Par ailleurs, cet apprentissage s'avère nettement supérieur dans la condition intentionnelle. À l'opposé, les personnes âgées ne démontrent aucun apprentissage de la séquence répétée peu importe la condition expérimentale. Puisque le rappel dans la condition intentionnelle s'avère supérieur chez les jeunes adultes, nous concluons que les différences observées entre jeunes adultes et personnes âgées dans la condition incidente ne sont pas attribuables à l'utilisation de stratégies explicites.

Abstract

Recent findings (Turcotte, Gagnon & Poirier, 2001) indicate that incidental learning of visuo-spatial supra-span sequences (Hebb's paradigm) declines with old age. In this task, randomly positioned squares light up one after another on a computer screen. Using finger pointing, participants have to recall the sequence of squares immediately after its presentation. Incidental learning is expressed by better recall of the embedded repeated sequence, which is presented 8 times (every 3rd trial for a total of 25 trials). The goal of this study was to examine whether awareness of the repetition has any effect on sequence learning and consequently could explain age group differences. We administered the visuo-spatial supra-span learning task to 45 young and 47 older adults. Participants were submitted to incidental or intentional learning instructions. In the intentional condition, participants were informed of the repeated sequence and were signalled when it appeared on the screen. Results showed that the elderly participants were impaired on this task even when tested under intentional instructions. In contrast, young adults showed significant learning of the repeated sequence under both conditions. However, their learning rate was significantly higher when informed of the occurrence of the repeated sequence. We conclude that age differences on this task do not result from better use of conscious strategies by young adults. Instead, we suggest that the differences are caused by a greater sensitivity to interference in older adults when the learning material comprises visuo-spatial information.

Table des matières

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An important skill for our continuous adaptation to a changing world consists in the ability to record and react to recurrent patterns or regularities in the physical, social or even internal environment (Doré & Mercier, 1992). Perception and learning of recurrences such as sequences of events occur when one demonstrates increasing response speed and/or accuracy to those regularities. Learning of regular patterns can occur explicitly or implicitly depending on the nature of the situation and/or given instructions. On explicit learning tasks, such as the explicit version of the serial reaction time developed by Nissen and Bullemer (1987) or the rote learning task (Kay, 1951), older adults typically show poorer learning than do younger adults (e.g. Arenberg & Robertson-Tchabo, 1977; Howard & Howard, 1989; 1992; 1997; Kay, 1951). In contrast, when assessed on implicit learning tests, older adults' deficits are either reduced substantially or completely eliminated (e.g. Cherry & Stadler, 1995; Frensch & Miner, 1994; Howard & Howard, 1989; 1992). The question arises whether age differences can successfully be explained by the implicit-explicit nature of the task, the latter emphasizing conscious recollection of the recurrent material?

Indeed, because some data suggest that older adults are also impaired on some incidental learning tasks, a definite answer to this question has yet to be provided. In one such series of studies, Turcotte, Gagnon and Poirier (2001) administered a spatial version of the Hebb paradigm to young and older adults. The supra-span learning task was developed by Hebb (1961) for the purpose of studying long-term memory trace formation. More specifically, this procedure examines the influence of incidental learning on short term recall of sequences of stimuli. In his initial experiment, Hebb submitted university students to an immediate serial recall task in which 24 sequences of digits were presented. Among the 24 sequences, one reappeared every third trial whereas the others were seen only once. Participants were not informed of the repetition of one of the sequences. Hebb found that immediate serial recall of the repeated sequence improved throughout the session. Interestingly, immediate serial recall of the random sequences did not seem to vary. Since Hebb's original observations, this repetition effect has been observed in both young and older adults using various types of verbal stimuli [numbers (e.g. Gagnon & Winocur, 1996; Heron & Craik, 1964), words (Turcotte, 2001), pseudo-words (Turcotte, 2001)].

In a recent set of studies, Turcotte, Gagnon and Poirier (2001) used a computerized version of the block tapping task (Corsi, 1972) to study incidental learning of visuospatial sequences. In the visuospatial version of Hebb's paradigm, a sequence of randomly positioned squares light up one after the other on a computer screen. Using finger pointing, participants have to recall the sequences of squares according to their order of appearance. As in the classical procedure and to insure that learning occurs incidentally, the participants were not informed of the repeated sequence. Two random sequences were introduced between each repetition, which appeared at trial 3, 6, 9, etc. Overall, twenty-five sequences were given.

In their first experiment, the sequences were always composed of 9 squares that were randomly positioned on the computer screen. Results showed that incidental learning was impaired in elderly participants. However, they also observed that older adults exhibited lower performance than young adults on random sequences indicating that storage demands exceeded older participants' capacity to retain information from such a long sequence of events. It is well known that span decreases as one ages (Kausler, 1994; Salthouse, 1991; Verhaeghen, Marcoen & Goossens, 1993). Although posthoc analyses did not indicate that learning was associated to span length, the possibility that older adults could not learn the task because of storage limits had to be considered.

For that matter, Turcotte et al. (2001) performed a second experiment to replicate their findings by decreasing storage demands through an individual adjustment of the sequence length based on each participant's span. Consequently, after a thorough assessment of their span, participants were submitted to the spatial version of the Hebb's supra-span task using a list length of span + 1 items. Interestingly, results of this study corroborated the age group differences previously observed, a finding that suggests that the effect of old age on incidental learning of sequences of spatial positions cannot be attributed to storage demands.

Surprisingly, these findings contrast with studies of Hebb effect using verbal stimuli in which older adults express normal learning of the repeated sequence (Gagnon & Winocur, 1996; Heron & Craik, 1964; Turcotte & al., 2001). Among the various interpretations that could explain age group differences on the spatial version of Hebb's task, awareness of the repeated sequence is certainly one that needs to be considered. Examination of participants' awareness was performed by Turcotte et al. (2001) using a post-experimental questionnaire from which participants were categorized into two groups according to the moment they noticed that a sequence was recurring: the early aware or middle aware and the late aware or unaware. They observed that most of both young and old participants noticed that a sequence was repeated. However, in both studies, statistical comparisons between the two groups suggested that sequence learning was not influenced by awareness of the repetition. This result corroborates the findings of McKelvie (1987) who demonstrated after a thorough post-experimental examination that the magnitude of repetition effect using a digit version of Hebb's paradigm was equivalent in both aware and unaware participants. However, other researchers have concluded that the Hebb effect was most likely related to participants' level of awareness (Kidd & Greenwald, 1988; Sechler & Watkins, 1991). Cunningham, Healy, and Williams (1984) argued that the Hebb repetition effect reflects the active processes of elaborative rehearsal that are considered as determinants of other repetition effects.

The measurement of awareness is a notoriously difficult topic to investigate (see Sechler & Watkins, 1991 for a review) and none of the studies mentioned above are truly conclusive. The awareness question, that is, the question of how to rule out the likeliness that conscious processing contaminates what is presumed to be nonconscious processing, needs to be examined with extreme caution. Assessing awareness is a very cumbersome task partly because of the lack of consensus on how it should be measured (e.g. Reingold & Merike, 1990). Over and above, an important query regarding the presence of the Hebb effect in young adults and the lack of it in older adults, is whether explicit processes need to intervene in order to observe the phenomenon. Considering the well known finding that old age alter conscious recollection of studied information, (Howard & Howard, 1997; Meulemans & Van der Linden, 1997) we wonder whether age-group differences emerged because young adults made use of explicit strategies.

This issue becomes even more sensitive considering that Hebb's supra-span requires explicit immediate recall of sequences. Indeed, learning is deduced through increased immediate serial recall accuracy of the repeated sequence.

In this study, our intention was to examine whether age group differences on learning of a supra-span sequence are caused by increased awareness of the repeated sequence in young adults. Intention to memorize a sequence of stimuli can be manipulated with appropriate instructions and should not invite the kind of debate that surrounds measures of awareness. In order to do so, participants were assigned to an intentional or an incidental condition as performed in others studies of incidental learning, (e.g. Curran & Keele, 1993; Frensch & Miner, 1994). One group was instructed of the presence of a repeated sequence and signaled when it appeared on the screen; the other was simply instructed to execute an immediate serial recall of each sequence of squares. Also, to clearly classify participants in the incidental condition as early, middle or late aware or unaware that a sequence was recurring a very exhaustive postexperimental questionnaire was administered. This questionnaire was inspired by the one developed by McKelvie, 1987).

We hypothesized that if age group differences are the result of conscious strategies used by young adults, older adults recall scores should significantly increase in the intentional condition in comparison to the incidental condition and differences between the incidental and intentional conditions in the young adult group should be minimal. Moreover, to avoid the ceiling effect previously observed in Turcotte et al.'s study

(2001), the number of squares in a sequence corresponded to the individual span plus two squares rather then span plus only one square.

Method

Participants

Ninety-two participants were recruited in this experiment: forty-five young adults and forty-seven older adults. The younger participants (22 men and 23 women) were undergraduate students enrolled in various academic disciplines. Their mean age was 22.93 years (range = 18 - 32, SD = 3.00). One young participant who reported to have ataxia was discarded. Older adults (24 men and 23 women) were drawn from a pool of volunteers who had participated in the past to unrelated experiments in our laboratory or were recruited through an ad placed in a local newspaper. Their mean age was 71.68 years (range = 66 - 80, SD = 3.45). All older participants were community dwelling volunteers. None of them reported to have experienced significant health problems usually identified to influence cognitive functions (neurological antecedent, psychiatric disorder, use of severe medication or alcohol and drug abuse). On the 3MS (Teng & Chui, 1987), all elderly participants obtained a score above the cut-off (80/100) associated with the likely presence of severe cognitive impairments. Participants were asked to wear their prescription glasses if needed during the experiment. The younger group had completed more years of education than the older adults, $t(66,4) = 7,48$, $p < 0,001$; the younger group averaged 16.2 years (range = 12 - 20, SD = 1.67) in comparison to 11.94 (range = 5 - 20, SD = 3.52) for the older group of participants.

The vocabulary sub-test of the Wechsler Adult Intelligence Scale (WAIS-III; Wechsler, 1972) was also administered as a measure of verbal ability. A significant group difference also occurred between young (M = 50.17, SD = 5.33) and elderly (M = 44.26, SD = 8.2) adults on this test, $t(90) = 4.09$, $p<0.0001$.

Material

Two tasks were administered to all participants: First, they were submitted to a computerized spatial span assessment test which was followed by the Hebb spatial supra-span paradigm. An IBM compatible Pentium 333 MHZ computer and an 18 inches video monitor were used to present the stimuli. The stimuli were squares that were randomly positioned on the computer screen. The squares were dark grey and were displayed on a light grey background. Their dimension was 484 mm^2. Their presentation was computerized using Mel 2 Professional. The sequential presentation of the squares was signalled by their colour changing from grey to white. Each presented sequence comprised all the squares displayed on the monitor. A beep was used as a signal to start recalling the sequence. For the assessment of the spatial span, the display could contain a number of squares that could decrease or increase from trial to trial. In the learning task, the number of squares could only vary from one participant to another as the number of squares on the display was adjusted to the participant's span.

A visual display was created for each length size of a sequence. The length of the sequences could vary between 2 and 13 squares. Therefore, a total of 12 displays were created. Spatial positions were maintained relatively constant between displays. Displays were built up progressively so that adjacent displays differed by the addition or removal of only one square. For example, the display that contained 4 squares shared three identical positions with the display made up of three squares. In addition, the average distance between the squares was maintained as equivalent as possible among displays (around 11,3 cm between each square). Squares were distributed on the entire screen display area.

In the first task that consists in the assessment of the span, 16 sequences were generated. Each sequence was randomly created and could appear only once. A sequence was composed of 2 to 13 squares. The length of each sequence was adjusted on each trial according to the participant's response on the preceding trial. A failed trial was followed by a shorter sequence whereas successful recall increased the following sequence by one square.

In the Hebb spatial learning task, the sequence length was adjusted to the participant's span and corresponded to span + 2 squares. For each display of spatial positions, 4 sets of 18 random sequences were developed to avoid a set effect. Each set contained a repeated sequence presented 8 times and 17 random sequences presented only once. The sets were randomly distributed among subjects. The repeated sequence was presented every third trial (trial 3, 6, 9… 24). The first presentation of the repeated sequence was at trial 3. Consequently, the first repetition appeared at trial 6. Overall, 25 sequences were presented in this task. A post-experimental questionnaire was administered after completion of the task.

Correction sheets for each set of sequences were used by the experimenter to note the answers that the participant gave by finger pointing. A camera was necessary to record the answers and allowed the experimenter to double-check scoring of the sequences.

Procedure

Participants were individually tested. Instructions for each task were displayed on the monitor. Participants were told that in both the spatial span and Hebb's tasks, the squares would light up one after the other on the computer screen and that after the beep, they would have to recall the sequence of squares using finger pointing. When unsure of the position of a square within the sequence, they were invited to take a chance. However, if they really had no idea of what square was in a specific position within the sequence, they were informed to point to the frame of the computer screen in order to leave that position blanked.

In both tasks, the beginning of a trial was indicated by the presentation of a trial number at the bottom of the screen for 1500 ms. Then, the display of dark grey squares on a light grey background was shown for 1500 ms. Then, the sequence of squares was presented. Each square became white one after the other for 1250 ms with an inter-item interval of 250 ms. The last square of a sequence was followed by the presentation of the starting display (the dark grey squares on a light grey background) for 600 ms which was followed by a 200 ms beep, which prompted the participant to start recalling the sequence. In the span assessment task, the participant was given 30 seconds to recall the sequence in the correct order. After this delay, participants saw the cue "ready?" at the bottom of the screen. When the participant agreed, the experimenter pressed the appropriate key to indicate to the program whether the participant failed or succeeded the trial. This procedure had the effect of increasing or decreasing the sequence by one square. In Hebb's task, participants had 20 seconds to recall the sequence by finger pointing which was followed by the presentation of the next sequence that began automatically.

At the beginning of each task, participants were seated comfortably at a distance of about 65 cm in front of the computer screen and were given instructions that described the task. Participants received 2 training trials with sequences of 3 squares. Training trials allowed the participant to become acquainted with the task and made sure that instructions were understood.

The assessment of span followed. The assessment was done using the up and down method developed by Watkins (1977, Brooks & Watkins, 1990). As mentioned earlier, using this method, the length of the sequence was adjusted on every trial based on the result of the previous trial. In the first trial, the sequence presented to the participant was made up of 4 squares. The 15 subsequent sequences were adjusted according to the participant's performances. Span estimate corresponded to the average length of the 13 last sequences, rounded off to the nearest number. This average length corresponded to the last 12 sequences presented among the 16 sequences and the length of the seventeenth trial if it would have been presented. Using this method, 50% of the sequences were correctly recalled and the span was defined as the length of sequence that had a 50% probability of correct recall. At the end of the task, the experimenter noted the estimate of the span computed by the program, which was used later for the Hebb supra-span learning task.

The Hebb supra-span learning task followed. Overall, the task was similar to the assessment of span with a few exceptions. The instructions told the participants that they had to recall again several sequences but this time the length of each sequence did not vary. Participants were assigned to the intentional or incidental condition. Participants in the intentional condition were made aware of the repeated sequence and were signalled when it appeared on the screen (trials 3,6,9...24). In addition, an asterisk was placed in front of the trial number to advise them that the repeated sequence was going to be presented. In contrast, participants in the incidental condition were not made aware of the repeated sequence. Participants were exposed to a total of 25 sequences in this task. The number of squares to recall within a sequence corresponded to the span of the participant plus 2 squares.

At the end of the testing session, participants answered a post-experimental questionnaire that was adapted to the condition in which they were tested. The questionnaire served to distinguish between aware and unaware participants who were tested in the incidental condition. The post-experimental questionnaire also allowed the identification of three subgroups of aware participants (Early, Middle or Late) on the basis of their reports on when they first noticed that a sequence was recurring. It was followed by a French translation of the WAIS-III Vocabulary subtest, the health questionnaire for the young adults and the 3MS for the older adults. The health questionnaire had been previously administered on the phone to the older participants at the time they were recruited. The testing session was completed within less than two hours.

Scoring

In the Hebb learning task, scoring was performed according to standard methods used with immediate serial recall paradigms. An answer was judged appropriate only if recalled in the correct position. With this method, the recall score corresponds to the proportion of squares pointed in their appropriate serial position. In tasks of that sort, learning can take place at different levels. A general practice effect could be observed as well as specific learning due to recurrence of the repeated sequence. General practice effects were examined by comparing recall scores of the random sequences to the baseline. Baseline corresponds to the first, second, third and fourth sequences, sequences 1 to three being three random sequences, whereas sequence 4 consists in the first occurrence of the repeated sequence. Random sequences were split into two blocks. The first block corresponded to the first half of random sequences that were presented after trial 4 (sequences 5, 7, 8, 10, 11, 13, 14, 16), whereas the second block corresponded to the last random sequences that were presented (sequences 17, 19, 20, 22, 23, and 25). To examine the evidence of specific learning of the repeated sequence, the second analysis compared the results of the random and repeated sequences. For this analysis, seven blocks were created which matched the occurrence of the repeated sequence. Recall scores for each repeated sequence corresponded to one block. Scores for the 7 blocks of random sequences were obtained by averaging the recall scores of the random sequences that preceded and followed each repeated sequence. For example, block 1 of the repeated trial corresponded to Trial 6 (the first repetition of the recurrent sequence) while block 1 of random sequences was the average of trials 5 and 7 recall scores. Evidence of specific learning of the sequence occurred when significant differences were observed between blocks of repeated and random sequences.

Results

Vocabulary and education

As we described earlier, the analysis of the Vocabulary subtest scores and education level yielded significant group differences. In order to evaluate the effect of these differences on learning, Pearson (*r*) correlations between on one hand, the WAIS-III vocabulary score and years of education and on the other hand, the recall scores on each of the 7 blocks of repeated and random sequences as well as baseline were computed. The resulting correlations are shown in Table 1. Because a number of significant correlations were obtained, analyses of covariance (Group X Condition) were computed on each of the variable found to be related with the vocabulary subtest score and/or the years of education. The analysis indicated that age group differences still remained when results on the WAIS-III vocabulary subtest or the years of education were taken into account. Therefore, the vocabulary score and years of education will no longer be considered and the following series of analysis will only consist in ANOVAs.

Insert Table 1 here

Assessment of span

A Group (young VS older adults) X Condition (incidental VS intentional) ANOVA was performed on the span scores. The analysis yielded a significant group effect, *F*(1,

88) = 7.61, $p<0.0001$. The analysis showed that young adults expressed a significantly higher average spatial span (M = 6.68, SD = 0.71) than the older adults (M = 5.54, SD = 0.53). However, the results showed no condition effect, $F(1, 88) = 0.07$, n.s., as well as no interaction, $F(1, 88) = 0.22$, n.s. This last result confirmed that before the learning phase, participants in both conditions were equivalent in terms of short term retention of spatial positions.

Hebb supra-span learning task

Two types of learning can occur in the Hebb supra-span learning task. One type of learning is unspecific and is associated with increased familiarization with the task as it unfolds. The second type of learning is specific and results from the recurrent presentation of the repeated sequence. We will begin the analysis of the Hebb supra-span learning task by examining the unspecific learning component of the task. Average immediate serial recall for baseline and blocks 1 and 2 of random sequences appear in Figure 1.

Insert Figure 1 here

The results indicate that young adults recalled the sequences with more accuracy than the older adults. A mixed design Age (young VS old) X Condition (incidental VS intentional) X Block of trials (baseline, block 1, or block 2) ANOVA with repeated measures on the last factor was performed. The analysis revealed a significant group effect indicating that young adults demonstrated better recall than older adults for the non-repeated sequences, $F(1, 88) = 18.88$, $p<0.0001$. No other main effects or interactions were significant. This last result indicates that participants did not become more proficient at recalling sequences while performing the task.

Figures 2 and 3 depict the specific learning profile of both age groups in the incidental or in the intentional condition respectively. As previously explained, the seven blocks of trials correspond to each occurrence of the repeated sequence. For the random sequences, the mean of the preceding and following sequences surrounding a repeated sequence was computed. Inspection of these figures suggests that in both conditions, younger adults showed better recall of the repeated sequence compared to the non-repeated sequence. This difference seemed to appear only on sequences 5 to 7 in the incidental condition (Figure 2) and much earlier in the intentional condition (Figure 3). In comparison, older adults did not seem to express specific learning of the recurrent sequence in both conditions.

Insert Figures 2 and 3 here

A mixed design Age (young VS old) X Condition (incidental VS intentional) X Block of trials (block 1 to 7) X Type of sequence (random or repeated) ANOVA with repeated measures on the two last factors was conducted. Effects (main and interactions) that reached the significant threshold ($p<0.05$) are presented in Table 2.

Insert Table 2 here

All main effects were found to be reliable: Condition, $F(1, 88) = 5.07$, $p<0.05$, Age, $F(1, 88) = 27.74$, $p<0.0001$, Blocks of trials, $F(6, 1144) = 9.53$, $p<0.0001$ and Type of sequence, $F(1, 1144) = 55.93$, $p<0.0001$. Moreover, some interactions were significant, including the four way interaction (Condition X Age X Block of trials X Type of sequence, $F(1, 1144) = 1.90$, $p<0.05$,). As a first step, this interaction was decomposed by calculating tests of simple main effects on the interaction Block of trials X Type of sequence for each age group and each testing condition. The first series of test compared scores on the repeated and the corresponding random sequences for each block of trials. In order to decrease chances of false rejection of the null hypothesis, type I error was reduced to .01. Simple main effects that reached this significant threshold are depicted in Table 3.

Insert Table 3 here

The analyses revealed a strikingly different pattern of results in the intentional condition than in the incidental condition for the younger group. In fact, the difference between the repeated sequence and the random sequences appeared only at block 5 in the incidental condition whereas it appeared from block 3 to 7 in the intentional condition. Most interestingly, the analysis revealed that there was little evidence of specific learning for the older adults. The significant difference between the repeated sequence and the random sequence observed in the first trial of the intentional condition could not be explained by a specific learning of the repeated sequence because better recall is observed on the random sequence ($\underline{M} = 0.57$) and not on the repeated sequence

(M = 0.41). The only significant difference observed between both types of trial in the elderly group that could indicate some form of specific learning appeared on trial 7 of the intentional condition. As hypothesized, no specific learning effect were obtained in the incidental condition for the older participants.

Moreover, in order to determine whether the participants became more proficient in the recall of the repeated sequence over blocks 1 through 7, post-hoc multiple comparison test (Tuckey, HSD, $p<0.03$) were computed for each conditions and each age group. Firstly, in the younger group a real progression over trial was observed in the intentional condition. In fact, the mean proportion of correct recall for the repeated sequence of the block 7 (M = 0.97), 6 (M = 0.87), 5 (M = 0.88) and 4 (M = 0.85) were deemed significantly different than recall on trial 1 (M = 0.63). However, the elderly participants did not seem to benefit from the knowledge that a repeated sequence was appearing regularly as the young participants did. A significant increase was only observed on trial 7 (M = 0.72). Secondly, the progression over trial is neater in the incidental condition than in the intentional condition. In the younger group, the only comparison that yielded a significant difference was between the mean recall of trial 5 (M = 0.81) and trial 1 (M = 0.56). No such differences was observed in the older adults group. This indicates that older adults do not demonstrate any learning of the repeated sequence in the incidental condition.

It is now worth examining whether learning of the repeated sequence differed between the two conditions. In order to do so, the Condition X Age X Type of sequence,

$F(1, 1144) = 15.05$, $p<0.0001$ was decomposed using simple main effects tests. A mixed design Condition (incidental or intentional) X Type of sequence (random or repeated) Anova with repeated measure on the last factor was computed for each age group. The analysis indicated that in the young adults group, recall of the repeated sequence was significantly higher in the incidental condition, $F(1, 43) = 13.97$, $p<0.001$. No difference was observed for the random sequences. Moreover, there was no significant difference of any sort between the two conditions in older adults.

Post-experimental questionnaire

As previously explained, a post-experimental questionnaire was administered to assess participant's awareness in the incidental condition. First, when we asked the participants whether they noticed anything particular about the procedure, the results showed that the younger adults ($\underline{M} = 0.68$) expressed with a significantly higher proportion that a sequence was recurring in comparison to the older adults ($\underline{M} = 0.19$, Fisher's exact probability test, $p<0.01$). However, when we directly asked them whether they would say that any set of digits was repeated during the experiment, the proportion of participants answering positively increased for both groups in such a way that the difference between the two groups was no longer significant. On the basis of this question, 20 of the 25 young and 18 of the 26 older adults were classified as aware of the repeated sequence. Also, participants who answered positively to this last question but who reported later in the questionnaire that they became aware that a repetition was occurring after the task ended were classified as unaware. Only four participants (one young and 3 elderly) were classified as unaware on the basis of this last criteria. Because older adults did not demonstrate any learning of the repeated sequence in both conditions, the following analyses about the effect of awareness of the sequence were only applied to young adults.

As previously explained, although very few young participants were categorized as unaware using the pre-established procedure, question 8 allowed to discriminate three subgroups of aware participants based on their reports on when they first noticed the repetition of the sequence (early, middle, or late). Consequently, of the 19 young participants classified as aware of the repetition, 0 were classified as early aware, 5 were classified as middle aware and 14 were classified as late aware. The unaware sub-group of participants was also included in the analysis. Figure 4 shows the mean proportion of correct serial recall for the repeated sequence in the young adults group as a function of their moment of awareness. Inspection of this figure revealed that the middle aware participants seemed to progress more like the unaware participants then like the late aware participants. Also, the late aware participants seemed to present a more progressive learning profile than the two other groups. This observation implies that the moment of awareness and to some extent, the level of awareness of the repetition, has no or little effect on sequence learning for the participants tested in the incidental condition.

Insert Figure 4 here

A mixed design, Aware (middle, late, unaware) X Block of trials (blocks 1,2,3,4,5,6,7) X Type of sequence (random or repeated) ANOVA with repeated measures on the two lasts factors, was computed. The analysis yielded main effects of block of trials, $F(6, 286) = 3.39$, $p<0.01$, type of sequence, $F(1, 286) = 7.58$, $p<0.01$, as well as the interaction Blocks of trials X Type of sequence, $F(6, 286) = 2.92$, $p<0.01$. However, no main effect of the aware variable, $F(2, 286) = 3.95$, n.s., and no interaction with that variable were observed. Then, post-hoc multiple comparison tests (Tuckey, HSD, $p<0.03$) were computed for the variable block of trials for each type of sequences (repeated or random). For the random trials, no differences were observed among the seven block of trials. In contrast, a progression over blocks of trials was observed for the repeated sequence, average serial recall for blocks 5 ($\underline{M} = 0.70$) and 6 ($\underline{M} = 0.73$) being significantly higher than for blocks 1 ($\underline{M} = 0.59$) and 2 ($\underline{M} = 0.61$). Thus, the analysis unravelled the same pattern of results for the middle aware, the late aware and the unaware participants.

Additional analyses regarding the post-experimental questionnaire were conducted. First, when we asked aware participants to reproduce the repeated sequence from memory, the results indicated that younger adults recall the repeated sequence with more accuracy in comparison to the older participants $t(32) = 2.42$, $p<0.05$. Moreover, we asked participants what type of strategy did they use to remember the sequences. On the basis of their answers, they were classified in one of four groups: visual, verbal, both (visual and verbal) and no specific strategy. The analyses revealed that in both testing conditions, there was no significant difference between the strategies used by the younger groups and the old adults, $X^2(4) = 6.07$, n.s. and $X^2(4) = 4.84$, n.s., for the incidental and the intentional condition respectively . This last analysis revealed that learning differences observed between the younger group and the older group cannot be explained by the nature of the strategy used to recall the sequences.

Discussion

The main goal of this experiment was to examine whether explicit strategies could explain age differences previously observed between young and elderly adults in a spatial version of the Hebb supra-span incidental learning paradigm (Gagnon & Winocur, 1996; Turcotte et al., 2001). In order to evaluate this interpretation, half of our young and older participants were informed that a sequence would reappear every third trial. One of the most interesting finding consists in the incapacity of older participants to learn the repeated sequence in both incidental and intentional conditions. In contrast, young adults demonstrated a significantly higher learning rate when tested under intentional instructions. Finally, as previously observed on several occasions, young adults displayed better incidental learning of spatial sequences than did older adults. Our findings strongly indicate that age differences previously observed in the incidental version of the task cannot be attributed to better use of explicit strategies in young adults.

As stated in the introduction, we predicted that if incidental learning of spatial supra-span sequences was mediated through conscious recollection, significant learning should take place in the older adults group when informed that a specific sequence was repeated. When introduced to the task, participants were verbally told that a sequence would appear every three trials and that a signal indicates when the sequence is displayed. To our surprise, older adults did not benefit from explicit knowledge of the repetition. Indeed average recall scores in the intentional condition did not differ at all from scores observed in the incidental condition. This finding confirms that older adults cannot learn a recurrent supra-span sequence when it is embedded within a series of random supra-span sequences, be the instructions incidental or intentional. The present findings confirm the observations previously made by Turcotte et al. (2001) but extend it to an intentional supra-span learning task. The fact that no incidental learning is observed once again in the older group cannot be explained by the awareness hypothesis.

The other finding that suggests that conscious processing does not mediate incidental learning is the larger learning effect found in the young adult group when tested under intentional instructions. We observed that recall performances increased much faster in the intentional condition and reached a level far beyond that observed under incidental encoding. The difference between the repeated sequence and the random sequences appeared only on sequence 5 in the incidental condition whereas it appeared at trial 3 to 7 in the intentional condition. Contrary to what was predicted, our results indicate that learning in the incidental condition was not caused by the use of explicit encoding and recall strategies. Even though young adults (as well as older adults) became aware of the repetition in the incidental condition, as it was revealed by the post-experimental questionnaire, they did not use the same overt strategies that participants from the intentional condition seemed to apply. In fact, in the incidental condition, awareness did not influence learning of the repeated sequence. Indeed, the analysis of the progression of learning over blocks of trials revealed the same pattern of results for the middle aware, the late aware and the unaware participants. This result is consistent with the study of Mckelvie (1987), in which he demonstrated that the Hebb effect occurred in both aware and unaware participants, and was of similar magnitude in both groups. This finding confirms the distinction that needs to be made between explicit recall strategies of long term information and recognition of previously seen information. In the incidental condition, participants do recognize that something was seen before but apparently, recognition did not trigger specific explicit strategies as it did under intentional instructions.

In addition, the strikingly different pattern of results displayed by the younger group in the intentional condition allows to eliminate the possibility that the Hebb effect observed is exclusively mediated by recognition of identity. The present results suggest that the Hebb repetition effect does not depend on conscious recognition of sequence identity or on explicit recall strategies. Indeed, results from the post-experimental questionnaire suggest that the Hebb effect is not a function of the degree of awareness of the repetition. This conclusion is consistent with the thrust of Hebb's (1961) contention that repetition of a sequence can set up some form of direct storage in long-term memory. However, the current results do not necessarily detract from Cunningham, Healy and Williams (1984) proposition, stated earlier, which suggests that active processes are involved in the Hebb repetition effect. In Hebb's procedure, subjects were required to recall each sequence by finger pointing immediately following its presentation, which Cunningham et al. (1984) argued encouraged elaborative associative strategies. However, the current data indicate that immediate serial recall does not necessarily engage the participant in active long term encoding of the repeated sequence. In contrast, when intentional instructions are given, elaborative association processes are triggered, and learning is increased dramatically. So, in the incidental condition, although acquisition of the repeated sequence does require active recall, emergence of learning does not rest on elaborative associative strategies of the sequence or on its conscious recognition.

At this stage, we wish to examine other interpretations that could explain age differences observed on supra-span learning of spatial sequences. Because we demonstrated that learning was impaired under both incidental and intentional instructions a parcimonious interpretation should apply to both types of learning. One possible interpretation associates learning deficits in older adults to their greater sensitivity to interference. A first observation that supports the interference interpretation comes from the results of Melton (1967) who reported that the size of the repetition effect decreases as the number of random trials between the repetitions increases. This hypothesis might be accommodated in a passive processing model in which consolidation is disrupted by greater interference (Melton, 1967; Frensch & Miner, 1994). This kind of interference has been observed in the verbal version of the Hebb paradigm. Indeed, Hebb's finding of a positive effect of list repetition has been shown to remain effective for up to five intervening novel trials before the list recurs (Melton, 1963). Although the existence of randomized list interference cannot be dismissed, it cannot be treated as a generalized effect typical of old age. As demonstrated by Turcotte et al. (2001), impaired supra-span learning for older adults has only been observed when sequences of spatial positions were used. In verbal supra-span learning tasks, older adults were not impaired. To become relevant, larger interference effects should be anticipated only when the spatial version of Hebb's task is employed to assess supra-span learning. Some findings seem to coincide with the proposition of a higher sensitivity to interference in the spatial domain. In their experiment, Gagnon and Winocur (1996), observed that supra-span learning was lower in both young and older adults in the spatial supra-span condition in comparison to the digit supra-span condition. In the older group, the differences between digit and spatial supra-span learning was such, that this group showed almost no learning, a finding that has been replicated on several occasions.

By the same token, a smaller spatial span in older adults could reflect greater sensitivity to interference. In this latter case, however, interference would develop within as well as between lists. It is now largely accepted that short-term retention of verbal and spatial informations are sustained by different and independant mechanisms: the phonological loop and the visuospatial scratchpad (Baddeley & Hitch, 1994). Although speculative at this point, it would certainly be worthwhile to examine whether sources of interference in the visuo-spatial domain could explain steady and larger age differences observed in spatial supra-span tasks. However, within list interference could only provide a partial explanation to age differences on supra-span-tasks since no significant correlation were found between span estimates and incidental or intentional learning (see also Turcotte et al., 2001). Nevertheless one cannot totally discard the influence of this form of interference. One should keep in mind that when sequences of nine spatial positions were administered to older adults, no learning at all was observed (Turcotte & al., 2001). In the present study, the average span of older adults was 5.5 and supra-span sequences were made of 7.5 items on average. The hypothesis of greater sensitivity to interference with old age also coincides with one of the propositions put forward by Howard and Howard (1997) to explain age differences observed in an implicit sequence learning task (SRT) where each stimulus of the repeated sequence was alternated with a random stimulus (such as 2R7R4R5R3R etc.). In their study, they noticed that when random stimuli were inter-mixed with the recurrent stimuli age differences were larger, which could be attributed to some form of interference generated by the presence of random stimuli. Further studies should examine interlist interference by reducing to one the number of randomized lists between two occurences of the repeated list. If the interference interpretation applies, age differences should decrease.

A second source of interference could be associated with the motor component of the task. In fact, participants performed immediate serial recall using finger pointing. Harrington et Haaland (1992) reported a decrease of implicit and explicit memory in older adults for motor sequences in a modified version of the serial reaction time task where a complex movement was necessary to execute the task, whereas no age differences was noticed in the classical version (Howard & Howard, 1989; 1992). In the classical SRT task, participants only have to press a key in response to a stimulus. In the spatial version of Hebb's paradigm, it appears legitimate to postulate that complex responses are requested. The response component of the task is highly important in sequence learning. Behavioural research suggests that spatial sequences learning tasks that include a motor response may rest on stimulus-based as well as response-based components, a suggestion upheld by a number of neuroimaging experiments that revealed implication of motor (primary motor cortex, premotor cortex, etc.) as well as nonmotor (parietal cortex, temporal lobe, etc.) brain areas (Stadler & Frensch, 1998). In our spatial version of Hebb's task, participants have to point the squares one after the other to recall the sequences. A successful answer could reinforce the memory trace created by the presentation of the sequence. However, if a participant makes a mistake (order or item) the response trace might interfere with the stimulus-based trace. Once again, this type of output interference would have to be greater in older adults in order to provide a coherent explanation of our findings. One way to evaluate this hypothesis would consist in substituting the finger pointing movement by a verbal answer.

Conclusion

The results of the present study suggest that conscious processing does not mediate incidental learning in the Hebb's visuo-spatial supra-span learning task. Young adults demonstrated better and larger learning rate when tested under intentional instructions. Also, results from the post-experimental questionnaire revealed that even if most of the participants were aware of the repetition in the incidental condition, they did not use the same overt strategies that participants from the intentional condition seemed to apply. In fact, in the incidental condition, awareness did not influence learning of the repeated sequence. Thus, in the incidental condition, participants do recognize that something was seen before, but apparently this form of recognition does not trigger specific explicit strategies as it does under intentional instructions.

The most interesting result from the present study consists in the incapacity of older participants to learn a repeated sequence of spatial positions under both incidental and intentional instructions. This finding strongly suggests that the lack of sequence learning in older adults is not caused by a lack of awareness of the repetition. Instead, we believe that visuo-spatial processing is impaired in old age and prevents the development of a durable memory trace. We suggest that two sources of interference might potentially explain the lack of learning in older adults.

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Table 1

Pearson (r) Coefficients of Correlation between WAIS-III Vocabulary Subtest Scores, Level of Education and the Immediate Serial Scores Obtained at the Different Blocks of Trials for the Repeated and Random Sequences as well as Baseline and Span (N = 92).

	WAIS	Education
Baseline	.22 *	.18
Blocks of repeated sequences		
Repeated Block 1	.04	.18
Repeated Block 2	.15	.24 *
Repeated Block 3	.12	.25 *
Repeated Block 4	.21 *	.22 *
Repeated Block 5	.48 ****	.37 ***
Repeated Block 6	.32 **	.29 **
Repeated Block 7	.16	.13
Blocks of random sequences		
Random Block 1	.12	.22 *
Random Block 2	.16	.27 **
Random Block 3	.08	.25 *
Random Block 4	.05	.07
Random Block 5	-.08	.03 (.81)
Random Block 6	.21 *	.30 **
Random Block 7	.23 *	.18 (.09)
Span	.26 *	.44 ****

* $p<.05$. ** $p<.01$. *** $p<.001$. **** $p<.0001$.

Table 2

Results of the Age (Young-Old) X Condition (Incidental-Intentional) X Type of Sequence (Repeated-Random) X Block of Trials (Block1 to 7) Mixed Design Analysis of Variance (N = 92).

Variable	*df*	Mean square	F
Block of trials	6, 1144	0.38	9.53
Type of sequence	1, 1144	2.20	55.93
Condition	1, 88	0.88	5.07
Age	1, 88	4.82	27.74
Condition X Type of sequence	1, 1144	0.24	6.22
Age X Type of sequence	1, 1144	0.61	15.38
Type of sequence X Block of trials	6, 1144	0.25	6.44
Condition X Age X Type of sequence	1, 1144	0.59	15.05
Condition X Age X Type of sequence X Block of trials	1, 1144	0.17	1.90

Note. Only effects that reached significance ($p<0.05$) are presented.

Table 3

Simple Main Effects Comparing Immediate Serial of each Occurrence of the Repeated Sequence and its Corresponding Block of Random Sequences for each Group and each Encoding Condition.

	df	Mean square	F
Older adults/Intentional condition			
1st occurrence	1, 1144	0.29	7.27
7th occurrence	1, 1144	0.31	7.83
Young/Intentional condition			
3th occurrence	1, 1144	0.69	17.54
4th occurrence	1, 1144	0.42	10.77
5th occurrence	1, 1144	0.73	18.76
6th occurrence	1, 1144	0.53	13.49
7th occurrence	1, 1144	1.21	30.82
Young/Incidental condition			
5th occurrence	1, 1144	0.60	15.33

Note. Only effects that reached significance ($p<0.01$) are presented.

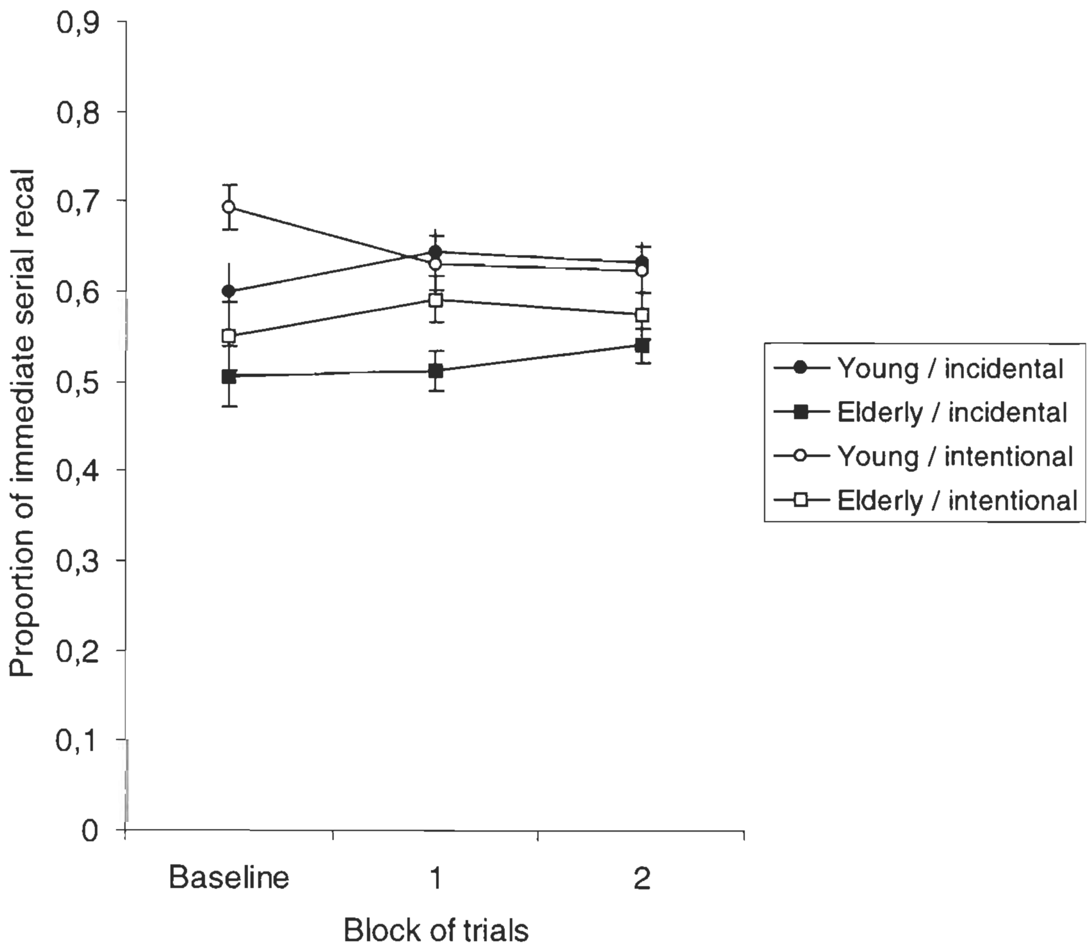
Figure Caption

Figure 1. Average immediate serial recall ($\pm$ SEM) for baseline and blocks 1 and 2 of random sequences.

Figure 2. Average immediate serial recall ($\pm$ SEM) for blocks of repeated and random sequences in the incidental condition.

Figure 3. Average immediate serial recall ($\pm$ SEM) for blocks of repeated and random sequences in the intentional condition.

Figure 4. Average immediate serial recall (+ SEM) for the repeated sequences in the younger group as a function of their awareness.



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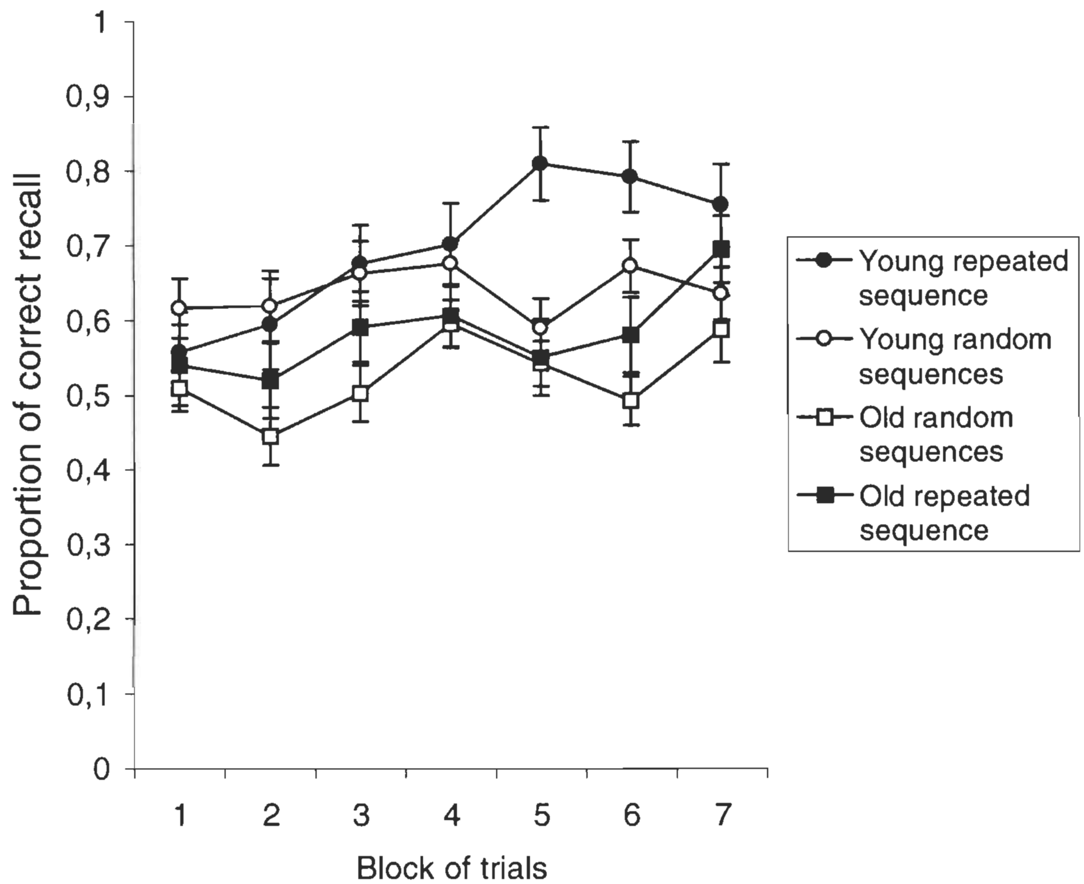
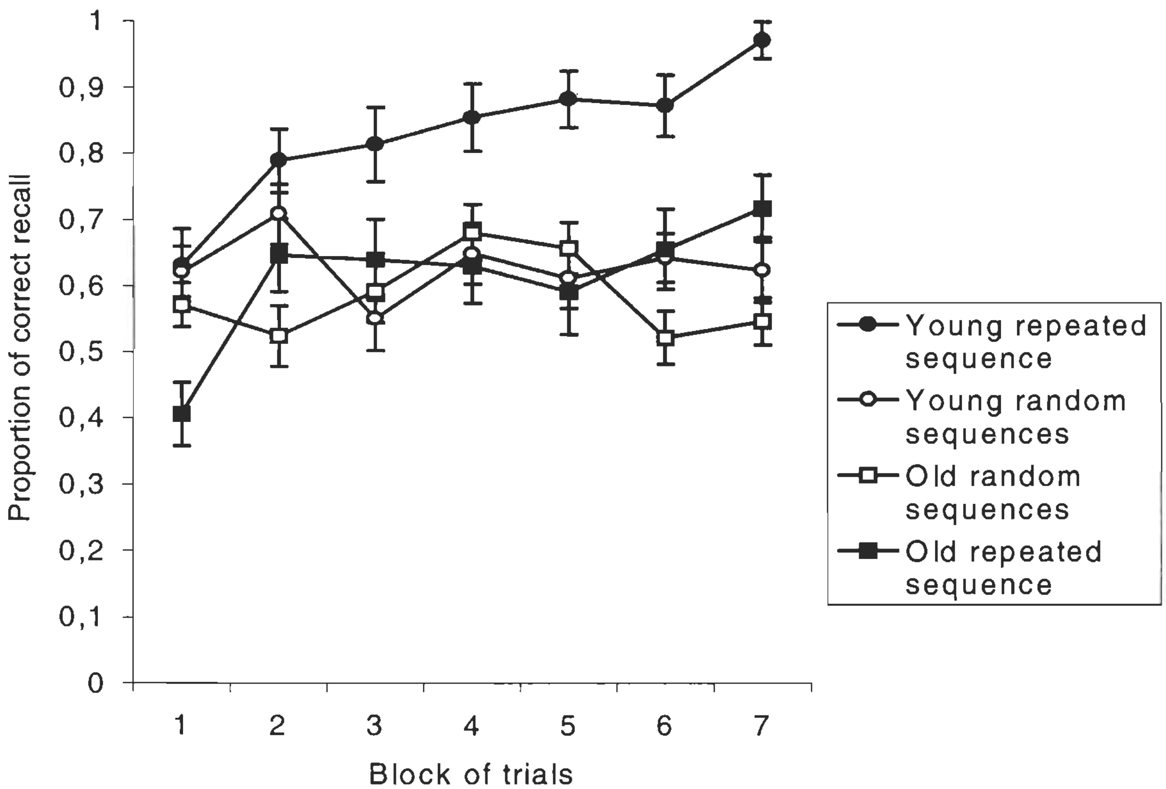
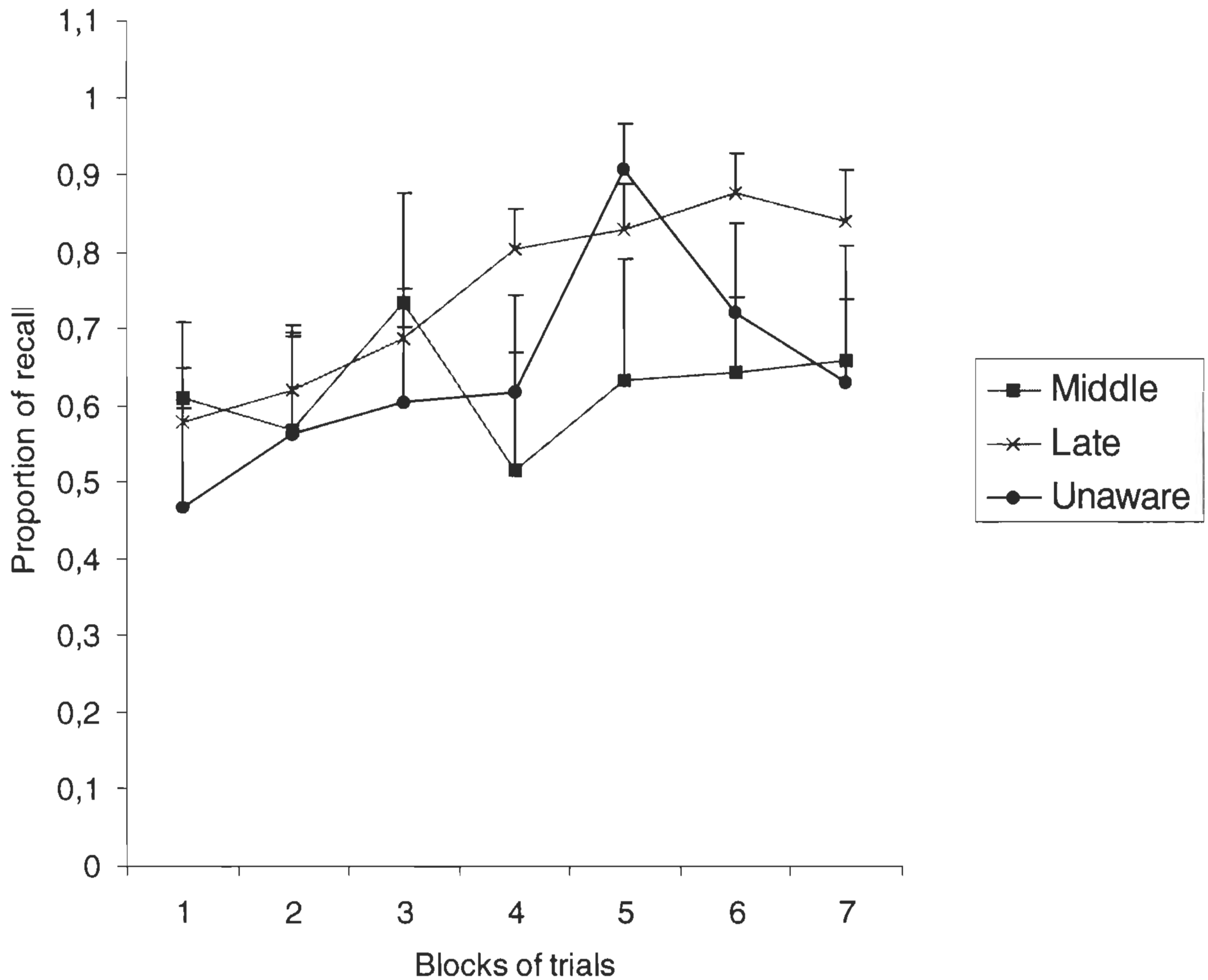
0,6
0,5
0,4
0,3
0,2
0,1
0
Proportion of immediate serial recal
Baseline
1
2
Block of trials
Young / incidental
Elderly / incidental
Young / intentional
Elderly / intentional



1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
Proportion of correct recall
1
2
3
4
5
6
7
Block of trials
Young repeated sequence
Young random sequences
Old random sequences
Old repeated sequence



Proportion of correct recall
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
1
2
3
4
5
6
7
Block of trials
Young repeated sequence
Young random sequences
Old random sequences
Old repeated sequence


1,1
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0,9
0,8
0,7
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0,4
0,3
0,2
0,1
0
Proportion of recall
1
2
3
4
5
6
7
Blocks of trials
Middle
Late
Unaware