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Mental imagery in a visuospatial working memory task and modulation of activation

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Ability to process information during a mental imagery task relying on visuospatial working memory and the advantages offered by the possibility of focusing the activation on specific items were examined in younger and older adults. The mental imagery task used for the study required participants to mentally move on a two-dimensional (5 × 5) or three-dimensional (3 × 3 × 3) matrix, while having to hold in memory either the whole pathway (WP condition) or just the final position reached (FP condition). The results revealed age-related differences in ability to modulate activation of visuospatial information. In particular, older adults, unlike the younger counterparts, did not benefit when the task allowed just part of the presented material to be considered. In particular, they drew less advantage from the three-dimensional matrix than the younger group. The findings are discussed in terms of the importance of processes reducing visuospatial working memory activation of irrelevant information and of the difficulties encountered by older adults in the modulation of activation.

Keywords: Ageing; Mental imagery; Visuospatial working memory.

Working memory (WM) is generally conceived as a temporary system that maintains and processes information (Baddeley, 1986). Although many studies have observed that tasks involving visuospatial working memory (VSWM) show larger age-related differences than verbal WM tasks (Bopp & Verhaeghen, 2007; Jenkins, Myerson, Joerding, & Hale, 2000; Lawrence, Myerson, & Hale, 1998; Myerson, Hale, Rhee, & Jenkins, 1999), other evidence has suggested that older adults are impaired in all complex memory span tasks requiring attentional control (Engle, Kane, & Tuholski, 1999), regardless of the type of information used for the task (Borella, Carretti, & De Beni, 2008; Vecchi, Richardson, & Cavallini, 2005). Some research has shown, for example, that older people perform more poorly than younger adults on complex VSWM span tasks requiring transformation, manipulation, and integration of visuospatial information (Cornoldi, Bassani, Berto, & Mammarella, 2007).

Elderly people have been shown to have particularly severe difficulties with complex VSWM span tasks, but to date there have been no systematic studies of age differences in visual mental imagery tasks. However, visual imagery tasks, requiring generation and manipulation of mental images, have been shown to rely on active VSWM, which in turns requires visuospatial information to be held in a temporary memory store and manipulated (see Baddeley, 1986; Cornoldi, Cortesi, & Preti, 1991; Cornoldi & Vecchi, 2003; Kerr, 1987). Available evidence on mental imagery in the elderly is still unclear but suggests that ageing is only sometimes associated with mental imagery impairment (Dror & Kosslyn, 1999; Palladino & De Beni, 2006). If, as a result of their difficulties in complex VSWM span tasks, elderly people are actually poorer in mental imagery tasks, it is important to understand what factors might be responsible. Indeed, a VSWM-related issue still debated concerns the specific
mechanisms underlying the lower WM capacity of
the elderly. Cornoldi et al. (2007) showed that
older adults not only have impaired performance
on complex VSWM tasks, but also commit a large
number of errors (inclusion errors) as a result of
inhibition failures. These authors suggested that
the elderly are impaired in modulating activation
of relevant information held in memory, because
of their limited attentional resources (see also
Borella, Delaloye, Lecerf, Renaud, & de Ribau-
pierre, 2009; Craik & Byrd, 1982). Indeed, mod-
ulating activation processes—presumably in
association with an attentional focus appropriately
directed towards relevant information (Cowan,
2005a, b)—allows activation to be increased for
relevant items and reduced for irrelevant, off-goal
information (De Beni, Palladino, Pazzaglia, &
Cornoldi, 1998). This is in line with the hypothesis
that inefficient suppression/inhibition of irrele-
vant information may account for age-related
differences between younger and older adults in
complex WM tasks (Borella et al., 2008; Hasher &
Zacks, 1988). In fact, older adults seem to en-
counter more difficulties than younger people in
suppressing activated information that becomes
irrelevant (see Borella et al., 2008; Robert, Bor-
ella, Fagot, Lecerf, & de Ribauipierre, 2009),
especially for highly activated irrelevant verbal
information (see De Beni & Palladino, 2004).
However, to our knowledge, this hypothesis has
never been applied to the case of spatial mental
imagery.

The present study examines the ability of
younger and older adults to modulate activation
using a complex VSWM span task that requires
not only the generation and maintenance of a
mental image, but also attentional control. To this
aim the Mental Pathway task (e.g., Kerr, 1987)
was administered. The task was developed to
explore the capacity to generate mental images
from verbal instructions and to maintain and
process them on the basis of successively pre-
sented information; participants have to imagine
moving within 2-D (5 × 5) and 3-D (3 × 3 × 3)
matrices following a pathway read out by an
experimenter, and then point to the final position.

It can be assumed that the Mental Pathway task
involves active VSWM processes since, for correct
execution, participants have to maintain the matrix
and path information in a temporary visuospatial
store and continuously change their current posi-
tion within the mental representation, reducing
the activation of positions previously reached. This
reduction will be radical if participants have to
keep in mind only the final position, since all other
positions previously encoded can be discharged
from memory; the reduction will be more modest
if also the whole pathway has to be recalled. In fact,
in order to broaden the observations on difficulties
met by older people in modulating the activation of
VSWM information during this task, a manipulation
involving two different conditions was added.
Participants were asked to imagine moving
through 2-D and 3-D matrices, mentally following
a pathway with two different activation requests:
recalling either final position (FP) or both the final
position and the whole pathway (WP). In the FP
condition, after presentation of each pathway,
participants had to recall only the last position of
the imagined pathway. Although they had to keep
track of the pathway, they had the advantage of
reducing the activation of previous pathway posi-
tions. In contrast, in the WP condition, participants
had to remember both the final position and the
whole pathway: They thus had to keep highly
activated all positions of the pathway, overloading
the VSWM system (which has limited capacity) in
order to respect the task instructions. We conse-
sequently expected younger adults to perform better
in FP than WP condition, but we predicted that
older adults would benefit less than younger
participants from the FP request, or even that
there would be no difference between FP and WP
conditions for older adults. Therefore, older adults
would tend to maintain activated all the informa-
tion instead of just the last presented position in FP
condition, such as in WP condition.

Furthermore, the 2-D and 3-D matrices used in
this present study allowed us to examine whether
the presence of a third dimension has implications
for the difficulty of the elderly in modulating
activation of VSWM information. Previous re-
search with younger adults in this context has
revealed a superiority effect of the 3-D over the
2-D matrix: Participants were more impaired in
processing a 5 × 5 (2-D) matrix than a 3 × 3 × 3
(3-D) matrix, even though both matrices comprise
a similar number of overall units (i.e., 27 cells in
3 × 3 × 3 vs. 25 cells in 5 × 5). Kerr (1987) inter-
preted this as dependence on image-processing
capacity, i.e., about three units in each direction:
Participants can easily process three units, irre-
spective of matrix type, 2-D (e.g., 3 × 3, total of
nine cells) or 3-D (e.g., 3 × 3 × 3, total of 27 cells),
but performance fell abruptly once capacity limi-
tation was exceeded (i.e., 5 × 5). However, further
researches (Cornoldi et al., 1991; Kerr, 1993)
showed that the 3-D matrix superiority over the
corresponding 2-D matrix is less evident in low spatial ability individuals, and Cornoldi and Mammarella (2007) suggested the effect might be due in part to the modulation of activation. In fact the exclusion of previously activated positions is facilitated with a 3-D matrix: The third (vertical) dimension might induce exclusion of one level when the new position reached involves a different level (superior or inferior), allowing consideration to be limited to the last level. This difference is interpreted as being due not only to the characteristics of the 3-D matrix and the subject’s need to reduce VSWM load when coping with three dimensions simultaneously, but also to the fact that the three dimensions should facilitate the delimitation of the portions of the whole matrix. Instead, the opportunity to modulate activation of previously presented positions is limited in a 2-D matrix since exclusion of matrix portions in a matrix of this type is not immediate as in a 3-D matrix; corroborating this, delimitation of portions of a 2-D matrix has been confirmed as facilitating the task (Kerr, 1987). Cornoldi and Mammarella (2007) found evidence supporting this hypothesis, showing that the typical advantage of the 3-D matrix in this task is lost when participants have to recall the whole pathway as well as the final position, since this condition prevents consideration of just a portion of the 3-D matrix. It follows that the difficulty in modulating activation of information experienced by older adults would result in their drawing less advantage from the 3-D matrix (over the 2-D matrix) than younger adults.

**METHOD**

**Participants**

One group of 34 younger adults (18 men and 16 women), aged 18–26 years \((M = 21.68, SD = 2.89)\), and one group of 30 older adults (18 men and 12 women), aged 58–81 years \((M = 65.80, SD = 6.15)\) participated in the experiment. All were native Italian speakers and volunteered to take part. They were recruited through advertisement in a newspaper kiosk in a town in north Italy. The older adults were selected on the basis of a health/physical questionnaire. Participants were excluded from the study if they met the “exclusion criteria” proposed by Crook et al. (1986), i.e., history of head trauma; any neurological or psychiatric illness; history of brain fever; dementia or any other state of consciousness alteration; use of benzodiazepines in the previous 3 months; use of illicit drugs; visual, auditory, and/or motor impairment; any symptomatic cardiovascular condition, breathing problems, or pathologies causing possible cognitive impairment. The older participants were active in cultural and social activities in their neighbourhood. The two groups did not differ in vocabulary score as assessed by the Wechsler Adult Intelligence Scale–Revised (WAIS-R; Wechsler, 1981) vocabulary subtest \((F < 1)\). Moreover, there were no significant age-related differences in years of education \((F < 1)\) (see Table 1).

**Materials**

The mental pathway task. This task used 3-D versus 2-D matrices composed of 3 cm cubic wooden blocks. A total of 24 trials were presented, 12 based on a 3-D matrix, 12 on a 2-D matrix.

Participants were asked to look at the matrix to memorise its mental representation as well as possible; the matrix was then covered up and participants had to mentally follow a pathway given verbally by the experimenter, imagining moving sequentially through adjacent blocks. For both types of matrix, to make the task more realistic, the metaphor of a visit to a complex building was used: The participants were told that the pathway could describe a pathway being made

| TABLE 1 | Means (M) and standard deviations (SD) of demographic variables by age group |
|---------|-------------------|-----------------|-------------------|-----------------|
|         | Younger adults    |                | Older adults      |                |
|         | \(M\) | \(SD\) | \(M\) | \(SD\) |
| Age     | 21.68 | 2.89 | 65.80 | 6.15 |
| Vocabulary | 36.18 | 10.01 | 40.37 | 12.42 |
| Years of education | 13.44 | 2.26 | 13.83 | 3.09 |
inside a building, each block corresponding to a room.

In the 3-D matrix \((3 \times 3 \times 3)\) type, participants were presented with a total of 12 pathways (6 in FP and 6 in WP condition), each involving seven statements of directions read out by the experimenter at the rate of 2 s per statement. The starting point of each pathway was the top left block. The statements of directions were left (LE)–right (RI), forward (FW)–backward (BW), up (UP)–down (DO). Any block, including those that were internal/hidden, could be included in the pathway; no block occurred more than once in a pathway.

Two task conditions were proposed: In the FP condition, the participants had to recall only the last position of the imagined pathway at the end of presentation of each pathway; in the WP condition, they had to remember the final position and then the whole pathway. Participants were told in advance whether they would have to recall only FP, or both FP and WP. For example, for the pathway RI, FW, LE, FW, DO, RI, UP, participants in the FP condition had only to point to the last position, i.e., the block on the top level, first row, second column; in the WP condition they had to point to the last position and then also tap out the complete pathway.

In the 2-D matrix \((5 \times 5)\) type, the task was the same as for the 3-D matrix, except that it involved cells in only two varying dimensions. Participants were presented with a total of 12 pathways (6 in FP and 6 in WP condition). As before, participants had to mentally follow a pathway on the matrix and then, depending on task condition, either point to FP or else point to FP and then tap out the whole pathway (WP). Again, participants were told in advance whether they would have to recall only LP, or both LP and then WP. Each pathway involved seven statements of directions read out by the experimenter at the rate of 2 s per statement. The statements of directions were left (LE)–right (RI), forward (FW)–backward (BW), diagonal (DG), i.e., forward diagonal from left to right. This latter direction was introduced in order to render the complexity of the instructions comparable for the two types of matrix (see also Cornoldi & Mammarella, 2007).

The starting point was the bottom-left block. The order of the matrices’ conditions was balanced.

For both 3-D and 2-D matrices, the order of FP and WP conditions was counterbalanced across participants. Further, in both matrices partici-
better than the older group on both matrices, 3-D, \( t(62) = 2.61, \ p = .011 \), and 2-D, \( t(62) = 4.36, \ p < .001 \), although the effect size of the age effect was higher in 3-D (Cohen’s \( d = 1.28 \)) than in 2-D (Cohen’s \( d = 0.48 \)) (see Figure 1).

There was no main significant effect of task condition \( (F < 1) \), but the Age group × Task condition interaction was significant, \( F(1, 62) = 4.53, \ MSE = 0.04, \ p = .037, \ \eta^2_p = .07 \). The interaction was due to the fact that, as it can be seen in Table 2, younger participants took a greater advantage from the FP request than the other group. Post hoc comparisons using Fisher’s \( t \)-tests revealed that younger adults performed better than the older group in both FP, \( t(62) = 4.20, \ p < .001 \), and WP condition, \( t(62) = 2.99, \ p = .004 \). In contrast, for the two age groups performance in FP and WP conditions did not differ, \( t(29) = -1.007, \ p = .322 \), and \( t(33) = 2.02, \ p = .052 \), respectively, indicating that the two task conditions had equal influence on recall of last position. Finally, although the Age group × Task condition × Matrix type interaction was not significant \( (F < 1) \), Table 2 shows that the superiority of the younger group over the older group with the 3-D matrix was more evident in FP than in WP condition.

To better examine a difficulty of participants to take advantage from the request of recalling only the final position, we calculated a score where individual differences on memory performance in WP condition was controlled for, as mean proportions of correct FP – mean proportions of correct WP. A 2 (age group: younger vs. older adults) × 2 (matrix type: 2-D vs. 3-D) mixed ANOVA was carried out on this score. A significant difference between younger and older adults, \( F(1, 62) = 4.53, \ MSE = 0.07, \ p = .037, \ \eta^2 = .07 \), was

### Table 2

Mean proportions (\( M \)) of correct responses (and SD) by condition (FP: final position vs. WP: whole pathway) and type of matrix (3-D vs. 2-D) by age group

<table>
<thead>
<tr>
<th></th>
<th>Younger adults</th>
<th></th>
<th>Older adults</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( M )</td>
<td>( SD )</td>
<td>( M )</td>
<td>( SD )</td>
</tr>
<tr>
<td>FP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-D matrix</td>
<td>0.71</td>
<td>0.26</td>
<td>0.40</td>
<td>0.30</td>
</tr>
<tr>
<td>2-D matrix</td>
<td>0.48</td>
<td>0.25</td>
<td>0.33</td>
<td>0.24</td>
</tr>
<tr>
<td>WP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-D matrix</td>
<td>0.66</td>
<td>0.25</td>
<td>0.46</td>
<td>0.29</td>
</tr>
<tr>
<td>2-D matrix</td>
<td>0.40</td>
<td>0.17</td>
<td>0.34</td>
<td>0.19</td>
</tr>
</tbody>
</table>

![Figure 1](image_url). Mean proportion of correct responses on the 3-D and 2-D matrices in both younger and older adults. Error bars represent standard errors.
found, older adults scoring lower than the younger group (\( M = -0.03, SD = 0.18 \), and \( M = 0.07, SD = 0.19 \), respectively).

Finally, a 2 (age group: younger vs. older adults) \( \times 2 \) (matrix type: 2-D vs. 3-D) mixed ANOVA was carried out on the raw number of positions correctly recalled considering only the whole pathway of the WP condition. Results showed a significant main effect of age group, \( F(1, 62) = 27.38, MSE = 2.92, p < .001, \eta^2 = .31 \); younger adults were found to recall more pathway positions than the older group (\( M = 4.80, SD = 0.49 \), and \( M = 3.21, SD = 1.6 \), respectively), confirming the memory superiority of the younger group.

**DISCUSSION**

The present study examined age-related differences between younger and older adults on a Mental Pathway task using different types of matrix (i.e., 3-D vs. 2-D) and conditions (i.e., FP vs. WP), which involved manipulation of the level of activation of the memory content. Although the task can involve different processes and strategies, including verbal strategies, it has been shown that mental imagery processes, relying on VSWM are critical to its execution (Cornoldi et al., 1991; Kerr, 1987). Consistent with these findings, participants in the present study reported having mainly used mental imagery.

Evidence to date on ageing and mental imagery is sketchy (Palladino & De Beni, 2006), but our findings show that when the imagery requires attentional control in VSWM, older adults are more impaired than younger counterparts. The main age effect found in the study therefore confirms the age-related decline in older adults in complex VSWM tasks requiring visuospatial information to be not only maintained but also manipulated (see Myerson et al., 1999; Vecchi et al., 2005). It is worth noting that in the current study, older adult performances, although poorer than those for younger adults, showed no floor effects.

The general difficulty older people had with the task may be due to a variety of factors shown to affect elderly performance, including age-related decline in: visuospatial abilities (e.g., Jenkins et al., 2000), speed of processing (e.g., Kemps & Newson, 2005), and working memory capacity (e.g., Baddeley, 1996). However, the specific interactions found in the study show that the elderly, over and above a general difficulty with the task, also ran into particular problems in specific conditions. In fact, our results provide specific information about the capacity of older adults to modulate the activation of information maintained in VSWM. In particular, our study highlighted two main differences between younger and older adults, which have implications for understanding the processes involved in processing visuospatial information.

The first concerns the difference between 3-D and 2-D matrices. The fact that the older adults did not benefit from the third dimension (over the younger adults) could also be due to the difficulty they encountered in modulating activation of VSWM information. The third (vertical) dimension seems to facilitate the exclusion of one level of the matrix when the new position reached involves a different level (superior or inferior). In other words, in the building metaphor, where subjects have to move from one floor to another in the 3-D matrix, participants can focus more easily on one part of the building (e.g., the first floor), removing attentional focus from the rest of the building (i.e., the other floors); delimiting parts of the building in the 2-D matrix case is possible but more difficult. In fact, magnitude of effect size was larger in 3-D than in 2-D. However, although supported by earlier evidence (Cornoldi & Mammarella, 2007), this interpretation should be approached cautiously, as further factors could contribute to the differences between the two matrices. For example, Vecchi, Tinti, and Cornoldi (2004) claimed that a poor performance with 3-D matrices—observed in congenitally blind people—might be due to a specific difficulty in processing and manipulating more than one pattern at a time, this being related to the need to represent a 3-D pattern as a series of 2-D surfaces. Moreover, age differences could also be related to speed of processing (e.g., Kemps & Newson, 2005). However, the lack of benefit for older adults with 3-D over 2-D matrices is in line with previous studies (Cornoldi et al., 1991; Kerr, 1993) showing a less evident 3-D matrix superiority (over the corresponding 2-D matrix) in low spatial ability individuals. In fact, there is also evidence that visuospatial abilities, in particular VSWM, are impaired in the elderly (Jenkins et al., 2000; Lawrence et al., 1998; Myerson et al., 1999).

The second main result was that, although the task condition was not statistically different in either age group, and younger adults performed
better than the older group in both WP and FP, was that, once individual differences in WP were controlled, older adults were more impaired in WP than in FP. This suggests that the older adults, who also had general difficulty in recalling the whole pathway, were unable to benefit from being able to reduce the activation of part of the pathway, and inhibit no-longer relevant positions. The result could also be due to a general difficulty of the older people in updating the position, thus forcing them to maintain the overall pathway active even when only last position was required.

In order to avoid ambiguities in the task affecting the instruction manipulations, we did not test the recall of the whole pathway in the FP condition (which explicitly stated this was not necessary); however, the present hypothesis allows us to predict that the performance for the whole pathway recall should present a greater difference between the two conditions in the younger group than in the older group.

Further studies are needed to confirm our conclusions, by introducing better control for the strategies actually used by participants and to examine the implications of different task constraints. For example, research into the effects of different presentation rates would be insightful, since age-related decrements have been shown to depend primarily on how quickly information can be processed (Kemps & Newson, 2005). In particular, it should be noted that (to avoid confounding through excessive number of trials) we did not vary the pathway length, and we also used two types of matrix. Possibly, other different task conditions might produce slightly different results. For example, the use of shorter pathways could allow examination of whether the same pattern of data can be observed in an easier condition, where the pathway length falls within the memory capacity of the elderly. Further research should also consider the practical implications of the present results, for example exploring whether VSWM deficit in older adults could be compensated through training in use of appropriate strategies, and examining the extent to which the building metaphor (suggested to the subjects) implied an egocentric representation of the environmental space. The implications are especially relevant in today’s ageing population: Strategy training and suitable representation of information can enhance the elderly’s quality of life by helping them overcome everyday orientation difficulties.

REFERENCES


