The Use of the Operand-Recognition Paradigm for the Study of Mental Addition in Older Adults

Catherine Thevenot,[1] Caroline Castel,[1] Juliette Danjon,[1] Muriel Fanget,[2] and Michel Fayol[2]

[1]FAPSE (Faculté de Psychologie et des Sciences de l'Education), University of Geneva, Switzerland.
[2]LAPSCO (Laboratoire de Psychologie Sociale et Cognitive), Centre National pour la Recherche Scientifique, France.

Objectives. Determining how individuals solve arithmetic problems is crucial for our understanding of human cognitive architecture. Elderly adults are supposed to use memory retrieval more often than younger ones. However, they might backup their retrieval by reconstructive strategies. In order to investigate this issue, we used the operand-recognition paradigm, which capitalizes on the fact that algorithmic procedures degrade the memory traces of the operands.

Method. Twenty-three older adults (M = 70.4) and 23 younger adults (M = 20.0) solved easy, difficult, and medium-difficulty addition and comparison problems and were then presented with a recognition task of the operands.

Results. When one-digit numbers with sums larger than 10 were involved (medium-difficulty problem), it was more difficult for younger adults to recognize the operands after addition than comparison. In contrast, in older adults, recognition times of the operands were the same after addition and comparison.

Discussion. Older adults, in contrast with younger adults, are able to retrieve the results of addition problems of medium difficulty. Contrary to what was suggested, older participants do not seem to resort to backup strategies for such problems. Finally, older adults' reliance on the more efficient retrieval strategy allowed them to catch up to younger adults in terms of solution times.

Key Words: Numerical cognition—Arithmetic—Elderly adults—Memory retrieval—Backup strategies.

THE study of mental arithmetic strategies in elderly individuals can help to determine how and when arithmetic facts are retrieved from memory, which is crucial to understanding human cognitive architecture. Simple addition problems can be solved through retrieval of the result from a table-like network stored in long-term memory (Ashcraft, 1992). However, if the answer is not strongly associated with the operands, it cannot be retrieved and algorithmic computations have to be implemented (Campbell & Xue, 2001).

Geary and Wiley (1991) found that elderly participants use the retrieval strategy more frequently than younger participants to solve addition problems (Duverne & Lemaire, 2005). Still, when only retrieved problems were considered, older participants were slower than younger ones. This was not due to central processes such as speed of retrieval but rather to processes such as digit encoding, strategy selection, and answer production. In addition to a slowing down in these peripheral aspects, the authors suggested that older adults could sometimes resort to backup strategies to verify the accuracy of the retrieved answer. Because in Geary and Wiley's study verbal reports were classified in only one category, it was not possible to determine if retrieval was followed by backup strategies.

More generally, we have shown that the use of verbal reports can be misleading (Thevenot, Castel, Fanget, & Fayol, 2010). Kirk and Ashcraft (2001) expressed concern about such a methodology and remarked that automatic mental processes, such as retrieval, are not accessible to consciousness. Thus, we developed a paradigm that does not rely on verbal reports (Fanget, Thevenot, Castel, & Fayol, 2011; Thevenot, Fanget, & Fayol, 2007) and takes advantage of the fact that algorithmic computation degrades the memory traces of the operands involved in the calculation (Thevenot, Barrouillet, & Fayol, 2001). This degradation results both from a memory decay phenomenon (Towse, Hitch, & Hutton, 1998) and from the sharing of attention among the operands, their components and the intermediary results to be reached to solve the problem (Anderson, 1993). In contrast, a comparison problem makes it necessary to keep the numbers in memory without any transformation. Thus, if operands are more difficult to recognize after addition than comparison, we can assume that algorithmic procedures have been used. In contrast, if the difficulty is the same in both conditions, the operation has most probably been solved by retrieval, a fast activity that does not imply operand decomposition.

In the present study, younger and older adults were tested on one-digit addition of easy and medium difficulties as well as on difficult two-digit additions. Regardless of age group, we expect easy problems to be solved through retrieval and difficult problems to be solved through algorithmic procedures. Therefore, we expect recognition times of the operands to be the same after addition and comparison

Received July 26, 2011; Accepted February 26, 2012
Decision Editor: Rosemary Blieszner, PhD

when easy problems are solved by young and older participants. In contrast, recognition times of the operands should be longer after addition than comparison for difficult problems. More importantly, if older adults do not resort to backup strategies to solve problems of medium difficulty, the difference in recognition times of the operands between addition and comparison should be observed only in younger participants whereas recognition times should be the same in older adults whatever the task to be performed.

Method

Participants

Twenty-three elderly adults aged 60–88 years (*M* = 70.4; standard deviation [*SD*] = 9.81) were recruited in the experimenters' family circles. All of them were in excellent health, reached high school, and scored higher than 27 (*SD* = 1.2; *M* =28.9) on the Mini-Mental-State Examination (Folstein, Folstein, & McHugh, 1975). Younger participants were 23 students aged 17–30 years (*M* = 20.0; *SD* = 2.8). Older adults scored 88 on an arithmetic fluency test whereas younger adults scored only 53 on average. This research was approved by the ethics committee of our institution.

Materials and Procedure

Experimental trials consisted of four numbers self-presented sequentially: the first and the second operand, an answer, and a target. When a number appeared on screen, the preceding number disappeared. Eight easy problems were composed of numbers between one and nine, the sums of which never exceeded 10. Eight problems of medium difficulty were composed of numbers between four and nine, the sums of which were larger than 11. Finally, eight difficult problems were composed of two-digit numbers between 13 and 49. Trials were preceded by either "A" for addition or "C" for comparison. In the addition condition, participants had to decide if the third number corresponded to the sum of the first two numbers. In the comparison condition, they had to decide whether this third number fell between the two previous numbers. Half of the trials required a no answer. For additions, this erroneous answer corresponded to the correct answer ± 1. For comparisons, this number corresponded either to the first operand plus one or the second operand minus one. For the recognition task, trials were associated with a target (i.e., fourth number) that could correspond to the first operand, the second operand, or one of the operands ± 1. Recognition times of the target and self-presentation times of each number were recorded.

Ninety-six experimental trials were presented but in order to prevent participants from adopting an active strategy of memorization of the operands, we integrated 192 fillers from which the recognition task was absent. Participants were then presented with 288 trials presented randomly using the Eprime software.

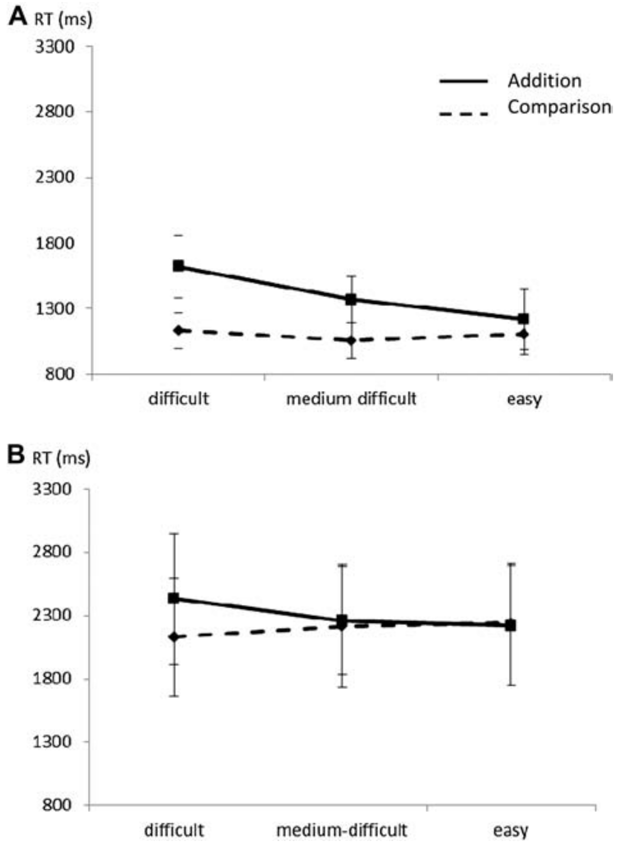

Figure 1. Recognition times (in ms) of the target (and confidence intervals) as a function of task and problem complexity for younger (1A) and older participants (1B).

Results

The rates of correct responses to the problems were high (.96), which confirmed that participants paid attention to the task. In our previous studies (e.g., Thevenot & Oakhill, 2005), the rates of correct recognition appeared to be a less sensitive measure than recognition times. Therefore, we will concentrate our data analysis on recognition times.

Recognition Times of the Operands

A 2 (Group: younger and older adults) × 3 (Problem complexity: Difficult, of medium-difficulty, and easy) × 2 (Task: addition and comparison) analysis of variance (ANOVA) with the first factor as a between-subject measure and the last two factors as repeated measures was performed on the mean recognition times of the operands (Figure 1). The three-way interaction between group, problem complexity, and type of problem was not significant. However, because precise predictions were formulated, they were tested using a series of planned comparisons. As expected, it took longer for young participants to recognize the targets after addition than comparison when difficult problems ($F(1, 44) = 27.74$, $\eta_p^2 = .39$, $p < .001$) and problems of medium difficulty ($F(1, 44) = 7.37$, $\eta_p^2 = .14$, $p = .009$) were

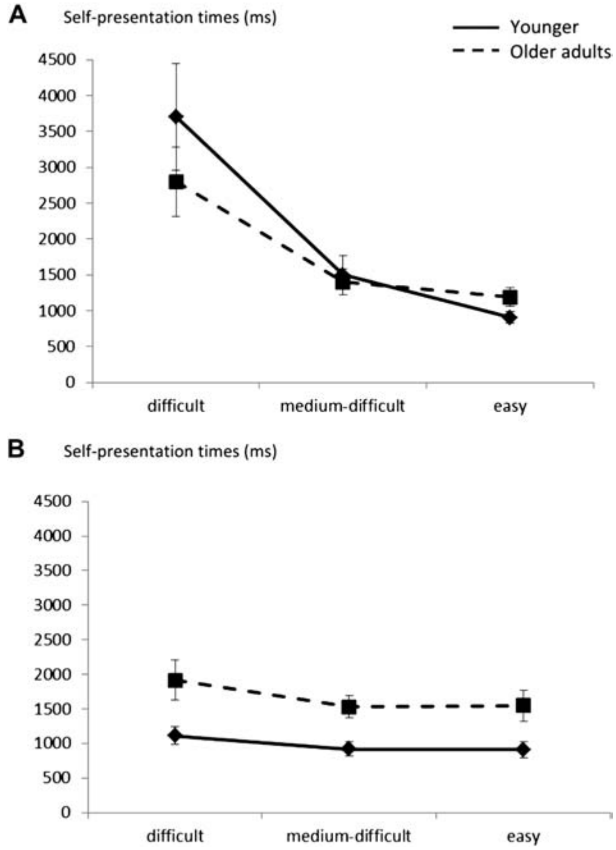

Figure 2. Self-presentation times (in ms) of the second operand (and confidence intervals) as a function of group and problem complexity for addition (2A) and comparison (2B).

involved. In contrast, for easy problems, the difference in recognition times between addition and comparison was not significant, $F(1, 44) = 1.33$, $p = .26$. Whereas the same patterns as in young participants were observed among older participants for difficult ($F\ (1, 44) = 10.81$, $\eta^2_p = .20$, $p = .002$) and easy problems ($F < 1$), it was different for problems of medium difficulty as there was no difference in recognition times between addition and comparison ($F < 1$).

Self-presentation Times of the Second Operand and the Proposed Answer

Two ANOVAs with the same design as before were conducted on the second operand and proposed answer self-presentation times. The second operand was self-presented longer for addition (1,916 ms) than for comparison (1,321 ms), $F(1, 44) = 46.07$, $\eta^2_P = .51$, $p < .001$ (Figure 2). In contrast, the proposed answer was self-presented longer for comparison (1,982 ms) than for addition (1,506 ms), $F(1, 44) = 23.21$, $\eta^2_P = .35$, $p < .001$. These results show that participants performed the addition as soon as the second operand appeared on screen.

There was a marginal effect of group on the second operand ($F(1, 44) = 3.58$, $\eta^2_P = .08$, $p = .07$) showing that it was self-presented longer for older than younger participants. More importantly, this effect interacted with the task and the problem complexity, $F(2, 88) = 8.14$, $\eta^2_P = .16$, $p < .001$. For difficult addition, young participants (3,704 ms) were slower than older ones (2,797 ms), $F(1, 44) = 4.47$, $\eta^2_P = .09$, $p = .04$; for addition of medium difficulty, there was no difference between young (1,499 ms) and older adults (1,402 ms), $F < 1$; and for easy problems, older adults were slower (1,187 ms) than younger ones (905 ms), $F(1, 44) = 14.92$, $\eta^2_P = .25$, $p < .001$. For comparison, the self-presentation of the second operand was always longer in older than younger adults ($F(1, 44) = 28.30$, $\eta^2_P = .39$, $p < .001$; $F(1, 44) = 43.31$, $\eta^2_P = .50$, $p < .001$; and $F(1, 44) = 27.49$, $\eta^2_P = .38$, $p < .001$ for difficult, medium-difficulty, and easy problems respectively).

Discussion

The results we obtained here in younger adults replicate those reported in Thevenot et al. (2007): For easy problems, recognition times of the operands were the same after addition and comparison but they were longer for addition than comparison when difficult and problems of medium-difficulty were solved by participants. These results suggest that students retrieve the result of addition problems when their sum is lower than 10 but mainly use reconstructive strategies when addition problems are of greater difficulty. As expected, the results we obtained in older adults were the same for easy and difficult problems. However, for medium-difficulty problems and in contrast with younger participants, older ones did not exhibit longer recognition times of the operand after addition than comparison.

These results support previous studies' conclusions that revealed age-related differences in strategy repertoire and distribution, with older adults who seem to use retrieval strategies more frequently than younger ones (e.g., Allen, Ashcraft, & Weber, 1992). This difference in strategy between younger and older adults could be due to cohort differences rather than to developmental ones. Indeed, Schaie (1983) reported such differences for basic numerical skills, with later cohorts generally showing relatively poor basic skills. Similar conclusions were reached in Europe where children from the 1920s were better arithmeticians than children from the mid-1990s (Dejonghe et al., 1996). These differences might be related to greater emphasis on rote memorization of basic facts during the elementary school years for earlier cohorts. If, as suggested here, older adults retrieve simple arithmetic facts more often than younger ones, it explains why the former generally outperform the latter in multidigit mental addition (e.g., Green, Lemaire, & Dufau, 2007). Complex calculation solving requires reaching a series of subgoals either through retrieval or counting. Because, generally, retrieval is faster than counting, good retrievers are necessarily quicker than not-so-good ones in complex mental calculation.

In replication of previous studies, we have shown here that when both older and younger participants solve problems by retrieval, solution times are shorter in younger than older adults. As already mentioned, this might not be due to speed of information retrieval but rather to a slowdown in peripheral processes. This would explain why older participants are slower than younger ones on comparison problems. Nevertheless, for addition, Geary and Wiley (1991) suggested that longer solution times in older than younger adults for problems solved through retrieval was also due to backup strategies implemented in order to verify the accuracy of retrieval. The novelty in the present research is that our results suggest that older participants do not resort to backup strategies for one-digit addition problems. Therefore, older adults seem to be good retrievers and do not behave as perfectionist individuals who prefer to backup retrieval with reconstructive strategies (Hecht, 2006).

Interestingly, whereas for very easy problems the same strategy in younger and older adults leads to different solution times, for one-digit problems of medium difficulty, different strategies lead to similar solution times. This finding supports argument of Charness (1981) that decreases in the overall rate of information processing typically associated with aging, such as retrieval, can be compensated for by the use of more efficient problem solving strategies (see also Fox & Charness, 2010, Grady, 2008, and Thevenot & Oakhill, 2006, for similar results in individuals with low capacities in working memory).

FUNDING

This work was supported by the Swiss National Science Foundation (Grant Reference: 100014-118306).

CORRESPONDENCE

Correspondence should be addressed to Catherine Thevenot, Faculté de Psychologie et des Sciences de l'Education, University of Geneva, 40 Boulevard du Pont d'Arve, 1211 Geneve 4, Switzerland. E-mail: catherine.thevenot@unige.ch.

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