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Decision-making competence in older and younger adults: Which cognitive abilities contribute to the application of decision rules?

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Abstract

Older adults perform worse than younger adults when applying decision rules to choose between options that vary along multiple attributes. Although previous studies have shown that general fluid cognitive abilities contribute to the accurate application of decision rules, relatively little is known about which specific cognitive abilities play the most important role. We examined the independent roles of working memory, verbal fluency, semantic knowledge, and components of executive functioning. We found that age-related decline in applying decision rules was statistically mediated by age-related decline in working memory and verbal fluency. Our results have implications for theories of aging and decision making.

Keywords: Aging, Decision-making competence, Memory, Executive functioning, Individual differences

The ability to make good decisions plays an important role in older adults' ability to achieve successful life outcomes and maintain independent living (Mather, 2006; Salthouse, 2012). Despite growing interest for the aging decision maker (e.g., Bruine de Bruin, Strough & Parker, 2014), relatively little is known about the relationship between aging and decision-making competence (Hess, Strough, & Löckhenhoff, 2015).

Some decision-making skills decrease with age (Bruine de Bruin, Parker, & Fischhoff, 2007, 2012; Del Missier et al., 2013; Queen & Hess, 2010), threatening the quality of older adults' decision outcomes (Bruine de Bruin et al., 2007, 2012). One crucial decision-making skill that declines with age is the ability to apply decision rules when choosing between options that vary along multiple attributes, such as consumer products, pension plans, or health treatments (Bruine de Bruin et al., 2007, 2012; Parker & Fischhoff, 2005; Payne, Bettman, & Johnson, 1993). For example, the 'equal weights' decision rule involves choosing the option that has the highest overall perceived quality across attributes (Payne et al., 1993). Another decision rule, 'elimination by aspects', involves selecting those options that meet a minimum criterion for the most important attribute, then selecting options from that set if they meet a minimum criterion on the second most important attribute, and so on until only one option is left (Payne et al., 1993).

Three studies have observed that the ability to apply decision rules declines with age, but only considered a subset of cognitive abilities to explain this negative relationship (Bruine de Bruin et al., 2012; Del Missier et al., 2013, 2017). One found a role for age-related declines in general fluid cognitive abilities, as assessed with Raven's Standard Progressive Matrices, but did not consider other cognitive measures (Bruine de Bruin et al., 2012). The others found a role for age-related declines in working memory (Del Missier et al., 2013, 2017), even when taking into account age-related differences in sensory functioning and processing speed (Del Missier et al., 2017). Although semantic memory was unrelated to age, it also contributed to better performance on applying decision rules (Del Missier et al., 2013).

However, these three studies have two main limitations. First, they have not included measures of executive functions. Yet, research with young adults has suggested that the ability to apply decision rules is relied on the updating and inhibition components of executive functioning (Del Missier, Mäntylä, & Bruine de Bruin, 2010, 2012). Second, they have not distinguished between two semantic memory components that may be relevant to the comprehension and application of written decision rules (e.g., Del Missier et al., 2013; Finucane, Mertz, Slovic, & Schmidt, 2005; Finucane et al., 2002), but have differential relationships to age: (a) verbal fluency, which declines with age, and (b) semantic knowledge which increases with age (Baddeley, Emslie & Nimmo-Smith, 1992 vs. Rönnlund, Nyberg, Bäckman, & Nillson, 2005; Verhaeghen, 2003). Verbal fluency (especially letter fluency) involves executive processes that exert strategic control and performance monitoring in a verbal task (Rende, Ramsberger, & Miyake, 2000; Shao, Janse, Visser, & Meyer, 2014). Semantic knowledge supports words meaning, and is often defined as part of "crystallized intelligence" because it reflects information that has been acquired over the life span (Horn & Cattel, 1967; Verhaeghen, 2003).

The present study

The present study followed up on previous studies (Bruine de Bruin et al., 2012; Del Missier et al., 2013, 2017) by taking a more comprehensive approach towards understanding which specific cognitive abilities contribute to age differences in applying decision rules.

Building on the literature review above, we formulated two research questions: (1) Are there age differences in applying decision rules and in specific cognitive abilities? (2) Which specific cognitive abilities explain age differences in applying decision rules?

To answer these research questions, we examined age differences in performance on the Applying Decision Rules task of the Adult Decision Making Competence battery[1] (Bruine de Bruin et al., 2007). We also examined age differences in specific cognitive abilities, and tested their contribution to age differences in applying decision rules, including (a) working memory processes to hold information in mind and make mental comparisons between values, (b) semantic knowledge and verbal fluency to support the understanding and application of written decision rules, (c) executive processes needed to focus selectively on target options and attributes and to inhibit irrelevant ones. Each of these cognitive abilities is assumed to play a role in Applying Decision Rules, varies with age, and can be measured with instruments that have an Italian version (Del Missier et al., 2010; 2012; 2013).

In regards to the first research question, we expected that older adults would perform worse than younger adults in Applying Decision Rules (Bruine de Bruin et al., 2007), as well as on measures of verbal fluency, working memory, and executive functioning (Fisk & Sharp, 2004; Myiake, Friedman, Emerson, Witzki, & Howerter, 2000; Rypma, Prabhakaran, Desmond, &, Gabrieli, 2001; Park et al., 2002). The exception would be semantic knowledge, which tends to increase with age (Horn & Cattel, 1967). In regards to the second research question, we expected that age-related decline in Applying Decision Rules would be explained by a corresponding age-related decline in working memory (Del Missier et al., 2013, 2017). However, age-related decline in Applying Decision Rules performance should also be statistically explained by a corresponding age-related decline in executive functioning, given that the more age-sensitive aspects of working memory are probably related to executive control (Bopp & Verhaghen, 2005). Finally, we also expected that age-related improvement in semantic knowledge would partly counteract age-related decline in Applying Decision Rules, due to supporting the understanding of written decision rules (Del Missier et al., 2013).

Method

Participants

Participants included 50 younger and 50 older adults[2]. None had a history of psychiatric or neurological disorders or substance abuse. Younger adults were undergraduate psychology students at the University of Pavia, who received course credit for participating. Older adults were recruited through the local branch of the University of Third Age. Older adults scored 26 or higher on the Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975), thus showing no signs of dementia. Table 1 shows descriptive statistics, as well as *t*-tests and effect sizes for the age group differences. Both age groups were similar in terms of gender composition and years of education. The study was approved by the ethical committee of the Department of Brain and Behavioral Sciences of University of Pavia.

Measures

Applying Decision Rules. The Applying Decision Rules task was taken from the Adult Decision-Making Competence battery, which has been validated in terms of psychometric properties and relationships with real-world decision outcomes (Bruine de Bruin et al., 2007). We used the Italian version (Del Missier et al., 2010). Participants received 10 decision problems, each describing a different hypothetical consumer who wanted to buy a DVD player. Each decision problem involved 5 DVD players that differed in terms of the following features:

picture quality, sound quality, programming options, and reliability of brand. Participants were asked to select one or more DVD players, by implementing the decision rule specified for each consumer. Participants were asked to apply decision rules (e.g., equal weights, elimination by aspects, satisficing, and lexicographic rules), which have been identified as relevant to good decision making (Payne et al., 1993). The overall score reflected the percent of correct items (Cronbach's alpha = .75).

Working memory. We used the Backward Digit Span task of the Wechsler Adult Intelligence Scales (Wechsler, 1981), which is a standardized measure of working memory widely used in neuropsychological settings. It consisted of orally presented sequences that increased in length from 2 to 8 digits. After hearing each sequence, participants were asked to repeat it in reverse order. The overall score consisted of the total number of correctly recalled digits, prior to failing two consecutive sequences at any one span size (Cronbach's alpha = .63). Possible scores could range from 2 to 8.

Semantic memory and Verbal fluency. The vocabulary test (Primary Mental Ability; Thurstone & Thurstone, 1963) is a widely used measure of semantic knowledge (e.g. Bissing & Lusting, 2007; Del Missier et al., 2013; Lecce et al., 2017). Because it does not require verbal production of semantic responses, it avoids potential confounds with age-related problems in semantic access (e.g., Burke & Shafto, 2004). Participants were asked to select the correct synonym from a list of 5 alternatives, for each of 50 words, within an 8-minute period. Total scores could range from 0 to 50 (Cronbach's alpha = .63).

A letter fluency task was used to assess verbal fluency, following common practices in neuropsychological assessment (Carlesimo et al., 1996; Strauss, Sherman, & Spreen, 2006). Participants were asked to generate as many words as possible beginning with the letter "F", "A", and "S", allowing 60 seconds for each letter. The overall score reflected the total number of correct words generated for each letter. Proper names, places and words with the same suffix did not receive credit. The average intercorrelation[3] between the three letters was $r = .66$.

Executive Functioning. We used four separate measures that reflected the multiple components of executive functioning, and are commonly used in experimental and neuropsychological settings (e.g., Miyake & Friedman, 2012; Miyake et al., 2000).

First, we used a shortened version of the Stroop Test (Venneri et al., 1993) to measure inhibition ability (see also Del Missier et al., 2012; Miyake et al., 2000). The test involved three parts that displayed 30 stimuli each. The stimuli were disks and words representing colors. Color words in the first part (W) were printed in black ink, in the second part (C) disks were printed in colors ink and in the third part (CW) color words were printed in a conflicting ink color (e.g. the word "BLUE" written in red). Participants were asked to read the stimuli in each part as fast as possible. We recorded reaction time for W, C, and CW. The overall score was derived from the sum of W and C reaction time, and then subtracted from the CW reaction time. The average intercorrelation[3] between the W, C, and WC reaction times was $r = .56$. We applied a transformation[4] to scores so that higher scores reflected better performance.

Second, we used the Numerical Updating task to assess updating (Carretti, Cornoldi, & Pelegrina, 2007). Participants heard eight lists of ten numbers ranging from 15 to 99. For each list, they were asked to recall the three smallest numbers in the correct order of presentation. For this study we used the most complex lists that had been developed. Overall scores reflected the total number of correctly recalled items, and could range from 0 to 24 (Cronbach's alpha = .83).

Third, Part B of the Trail Making Test was used to assess shifting ability (Retein & Wolfson, 1985). It asked participants to connect, as quickly as possible, a series of numbers (1 to 13) and letters (A to N) that were randomly distributed on a sheet paper, alternating between number and letter in ascending order (e.g., 1-A-2-B, etc.). The total score was the total completion time in seconds. We applied a transformation[4] so that higher scores reflected better performance. Because our study included one session, it produced one total score, preventing the computation of internal consistency measures. In studies using multiple sessions, Cronbach's alpha is typically in the range of .70 - .90 (Giovagnoli et al., 1996).

Fourth, we employed the Modified Card Sorting Test (MCST; Nelson, 1976) to assess complex executive functioning, which was similar to a shortened version of the Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Talley, Kay, & Curtis, 1993). It involved four stimulus cards and two sets of 24 response cards. The four stimulus cards depicted one red triangle, two green stars, three yellow crosses, and four blue circles, respectively. The response cards depicted geometric figures varying in three categories: color (i.e., red, green, yellow, and blue), shape (i.e., triangle, star, cross, and circle), or number (i.e., one, two, three and four). The four stimulus cards were placed in front of participants. Their task was to match each response card with a stimulus card, so as to discover the correct rule for making a match (i.e., by the categories of color, shape and number). They were not told what the rule was, but they were told whether each match was correct or incorrect. After six consecutive correct responses, a participant was deemed to have discovered the rule. They were then told 'now the rules have changed' and asked to discover the next rule according to the same procedure. The test ended when participants correctly identified the three rules (for the categories color, shape and number) twice. The overall score reflected the number of rules correctly identified and could range from 0 to 6 (Cronbach's alpha = .93).

Statistical Analysis

To address our first research question, we conducted two-tailed independent-sample *t*-tests to examine age-group differences in performance on Applying Decision Rules, and in our measures of cognitive abilities (working memory, verbal fluency, semantic knowledge, complex executive function, shifting, updating, inhibition). We also computed Pearson correlations between age group, Applying Decision Rules performance, and cognitive measures (Table 2). The correlations between age group and other variables are point-biserial correlations, which reflect relationships between a dichotomous variable and a continuous variable. We applied the Bonferroni correction to the significance levels ($\alpha = .006$) of those tests that were executed separately for each cognitive measure, including independent-sample *t*-tests, correlations, and mediation analyses.

To address the second research question, we conducted mediation analyses to examine whether the relationship between age and Applying Decision Rules performance was statistically explained by the cognitive abilities. Following recommended methods (Baron & Kenny, 1986; Preacher & Hayes, 2008), we reported unstandardized estimates (*B*) from regression analyses to examine the pattern in Figure 1, including the relationship between the independent variable and the potential mediator (Path A), between the potential mediator and the dependent variable (Path B), and between the independent variable and the dependent variable both before controlling for the potential mediator (Path C) and after doing so (Path C').

Subsequently, we used a macro developed for SPSS (PROCESS; Hayes, 2013) which randomly selected 1,000 bootstrap re-samples from the dataset to compute the 95% bias-corrected confidence intervals for the relationship of the dependent variable and the independent variable through the potential mediator (Path C'). Mediation tests are considered significant when the confidence intervals do not include zero (Shrout & Bolger, 2002). Given that we adopted a Bonferroni-corrected alpha at .006, we have set the confidence interval to 99.4%. The bootstrapping approach is preferred over the Baron & Kenny (1986) and Sobel (1986) methods for examining mediation, because it has more statistical power, does not require a normality assumption, and provides better protection against type I error (MacKinnon et al., 2004; Preacher & Hayes, 2008; Shrout & Bolger, 2002).

We tested for mediation in two stages. First, we conducted separate single-mediation tests for each cognitive measure, so as to identify its contribution to the relationship between age group and Applying Decision Rules (see Figure 1). Second, we conducted a multiple-mediation test including those cognitive measures that were significant in the first step, so as to identify their independent contributions to the relationship between age group and Applying Decision Rules (see Figure 2).

Results

Are there Age Differences in Applying Decision Rules and in Specific Cognitive Abilities?

As seen in Table 1, we found a significant difference between age groups in the Applying Decision Rules task, with older adults performing worse than younger adults. Older adults also performed significantly worse on measures of working memory, verbal fluency, complex executive function, shifting, updating, and inhibition. In contrast, older adults performed better than younger adults with respect to semantic knowledge. As seen in Table 2, older age was significantly associated with lower performance on Applying Decision Rules and on all other cognitive measures. The exception was semantic knowledge, which showed significantly better performance among older adults.

Additionally, Table 2 also showed two other notable patterns. First, performance on

Applying Decision Rules was positively correlated to performance on all measures of cognitive abilities. Hence, working memory, verbal fluency, semantic knowledge and executive functioning were all relevant to Applying Decision Rules. Second, the measures of cognitive abilities were intercorrelated. That is, shifting, updating, inhibition, and complex executive functioning, were all positively correlated with each other as well as with working memory and verbal fluency.

What Specific Cognitive Abilities Explain Age differences in Applying Decision Rules?

First, we conducted single-mediation tests separately for each cognitive ability measure, following the bootstrapping approach (Preacher & Hayes, 2008). In each model, we entered age group as the independent variable, Applying Decision Rules as dependent variable and one cognitive ability measure as a potential mediating variable. Figure 1 represents the single-mediation model for each potential mediator. Table 3 reports the statistical values for the single-mediation model associated with each potential mediator.

After setting the Bonferroni-corrected alpha at .006, we found that (a) older age was significantly associated with better semantic knowledge and worse complex executive functioning, shifting, updating, and inhibition (Path A in Figure 1 and in Table 3); (b) higher scores for semantic knowledge, working memory, verbal fluency, and updating were significantly associated with better performance in Applying Decision Rules (Path B in Figure 1 and in Table 3); (c) the negative association between age group and Applying Decision Rules (Path C in Figure 1 and in Table 3) significantly increased after controlling for semantic knowledge and significantly decreased after controlling for working memory, verbal fluency, updating, shifting, and inhibition (Path C' in Figure 1 and in Table 3). Finally, results showed that older adults' lower performance on the Applying Decision Rules task was statistically explained by age-related increases in semantic knowledge, and by age-related decreases in working memory, verbal fluency, shifting, updating, and inhibition (see 99.4% CI in Table 3). The one exception was the complex executive function task, which did not significantly mediate the relationship between age group and Applying Decision Rules (Table 3). Possibly, the complex executive function task did not capture age-related changes relevant to explaining age differences in Applying Decision Rules, even though it did show significant correlations with age group and Applying Decision Rules (Table 2). Thus, the single-mediation analyses suggested that older adults' Applying Decision Rules performance benefited from their better semantic knowledge while being harmed by their worse performance on working memory, verbal fluency, shifting, updating and inhibition[5].

As our second step, we therefore conducted a multiple-mediation analysis that included as potential mediators all cognitive measures that were significant in the first step (see Figure 2). Doing so allowed us to assess the independent contribution of each potential mediator, despite its intercorrelations with the other tasks[6] (Table 2). The model followed the bootstrapping approach, with age group as the independent variable, Applying Decision Rules as the dependent variable and the cognitive measures as potential mediators. Figure 2 shows that the relationship between age group and Applying Decision Rules (Path C) was significantly reduced after taking into account all potential mediators (Path C'). Mediation was only significant through working memory, 99.4% CI [-5.35, -.57], and verbal fluency, 99.4% CI [-4.69, -.01]. Thus, older adults' lower performance on Applying Decision Rules were likely a reflection of age-related declines in working memory and verbal fluency.

Discussion

Applying decision rules is the ability to choose the best option from a set of alternatives, in accordance with specific criteria or goals (Payne et al., 1993). Good performance on this task requires having the knowledge and cognitive abilities for understanding and applying decision rules (Bruine de Bruin et al., 2007, 2012; Del Missier et al., 2010, 2017, 2013). The present study was designed to examine differences between younger and older adults in applying decision rules, and to identify which cognitive abilities play the most important role in explaining any age differences in performance. Our findings build on previous research (Bruine de Bruin et al., 2012; Del Missier et al., 2017, 2013), which had only considered subsets of these cognitive abilities. We report on two main findings.

First, older adults were less accurate than younger adults in applying decision rules, thus replicating previous findings (Bruine de Bruin et al., 2012; Del Missier et al., 2017, 2013). Moreover, older adults performed worse than younger adults on all cognitive measures, with the previously reported exception that semantic knowledge increased with age (Horn & Cattel, 1967).

Second, and more importantly, we found that the age-related decline in applying decision rules was statistically mediated by age-related decline in working memory and verbal fluency, even after taking into account other potentially relevant cognitive abilities. Although all other measures of cognitive ability showed significant relationships to applying decision rules in correlation analyses (Table 2), and a subset contributed to age differences in applying decision rules when considered as single mediators, only working memory and verbal fluency remained significant mediators in a multi-mediation model. These findings suggest that older adults' lower performance in applying decision rules may mainly be driven by age-related decline working memory and verbal fluency.

Possibly, applying decision rules requires working memory processes to hold information in mind and make mental comparisons between values (Del Missier et al., 2017). Hence, older adults' decline in working memory (Rypma et al., 2001) makes it harder to correctly apply complex decision rules. Additionally, Applying Decision Rules task may require verbal competence and strategic control abilities in the processing of verbal and numeric information, in order to understand the written descriptions of decision rules and to support their translation into procedures (Del Missier et al., 2013). As a consequence, older adults' poorer performance in verbal fluency (e.g., Mayr & Kliegl, 2000; Park et al., 2002) may have threatened the comprehension and strategic application of the complex rules presented in the task (Finucane et al., 2005, 2002). In addition, verbal fluency may involve fluid cognitive abilities (Roca et al., 2012), which tend to contribute to age-related decline in the application of decision rules (Bruine de Bruin et al., 2012).

Limitations

Like any study, our investigation had limitations that should be considered in future research. First, our data were correlational and cross-sectional in nature. We recruited relatively small convenience samples, in an extreme age-group design. Thus, our findings would be strengthened by replication with a large national life span sample followed over time. Such a longitudinal study would also allow for analyzing age as a continuous rather than as a dichotomous variable. A second limitation pertains to the limited reliability for some of the cognitive ability measures, which was lower than reported in previous studies (Tombaugh, Kozak, & Rees, 1999; Thurstone, 1948; Wechsler, 1981), potentially weakening our statistical power. Third, it has been suggested that, in addition to cognitive ability, good decision making requires motivation (Bruine de Bruin, McNair, Taylor, Summers, & Strough, 2015). Older adults report lower levels of motivation for difficult task that lack personal relevance (Löckenhoff & Carstensen, 2007; Hess, Queen, & Ennies, 2013) and recent findings suggest that age-related changes in motivation can affect the older adults' effort to make decisions (Strough, Bruine de Bruin, & Peters, 2015; Bruine de Bruin et al., 2015). Hence, future studies should examine whether age-related changes in motivation may affect performance also on a complex decision-making task as Applying Decision Rules. Finally, it would be interesting to analyze the specific decision-making processes and errors underlying younger and older adults' performance in Applying Decision Rules, through process tracing methodologies such as think-aloud protocols, eye-tracking, and mousetracing.

Conclusions and applied implications

Our findings suggest a need for interventions that reduce older adults difficulties in applying decision rules. One possible intervention strategy is to reduce the number of options, which makes decisions easier (Johnson, 1990; Leventhal, Leventhal, Schaefer, & Easterling, 1993; Mikels, Reed, & Simon, 2009; Reed, Mikels, & Simon, 2008; von Helversen & Mata, 2012). Another possible strategy is to provide clear instructions that help older adults to understand how to choose among a set of alternatives (Peters, Hess, Västfjäll, Auman, 2007; Strough et al., 2015). Finally, it could be helpful to train older adults, so as to help them to automatize the application of decision rules (Besedeš, Deck, Sarangi, & Shor, 2012, 2014; Johnson, 1990, 1993; Payne et al., 1993), thus decreasing demands on memory and executive control. In conclusion, a better understanding of older adults' strengths and weaknesses in the application of decision rules may provide insights relevant to designing interventions for promoting better decision making.

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Disclosures

The authors declare no conflict of interest.

References

Baddeley, A., Emslie, H., & Nimmo-Smith, I. N. (1992). *The speed and capacity of language-processing test*. Bury St. Edmunds, England: Thames Valley Test Company.

Baron, R. M., & Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of personality and social psychology*, *51*, 1173. http://dx.doi.org/10.1037/0022-3514.51.6.1173

Besedeš, T., Deck, C., Sarangi, S., & Shor, M. (2012). Age effects and heuristics in decision making. *The Review of Economic and Statistics, 94*, 580–595.
http://dx.doi.org/10.1162/REST_a_00174

Besedeš, T., Deck, C., Sarangi, S., & Shor, M. (2014). Reducing choice overload without reducing choices. *The Review of Economic and Statistics, 97*, 793–802. http://dx.doi.org/10.1162/REST_a_00506

Bissing, D., & Lustig, C. (2007). Who benefits from memory training? *Psychological Science*, *18*(8), 720-726. http://dx.doi.org/10.1111/j.1467-9280.2007.01966.x

Bopp, K. L., & Verhaeghen, P. (2005). Aging and verbal memory span: A meta-analysis. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *60*, 223–233. http://dx.doi.org/10.1093/geronb/60.5.P223

Bruine de Bruin, W. B., McNair, S. J., Taylor, A. L., Summers, B., & Strough, J. (2015). “Thinking about numbers is not my idea of fun”: Need for cognition mediates age differences in numeracy performance. *Medical Decision Making*, *35*, 22–26. http://dx.doi.org/10.1177/0272989X14542485

Bruine de Bruin, W., Parker, A. M., & Fischhoff, B. (2007). Individual differences in adult decision-making competence. *Journal of Personality and Social Psychology, 92*, 938–956. http://dx.doi.org/10.1037/0022-3514.92.5.938

Bruine de Bruin, W., Parker, A. M., & Fischhoff, B. (2012). Explaining adult age differences in decision-making competence. *Journal of Behavioral Decision Making, 25*, 352–360. http://dx.doi.org/10.1002/bdm.712

Bruine de Bruin, W., Strough, J., & Parker, A. M. (2014). Getting older isn't all that bad: Better decisions and coping when facing "sunk costs". *Psychology and Aging, 29*, 642–647. http://dx.doi.org/10.1037/a0036308

Carlesimo, G. A., Caltagirone, C., Gainotti, G. U. I. D., Fadda, L., Gallassi, R., Lorusso, S., ... & Parnetti, L. (1996). The mental deterioration battery: normative data, diagnostic reliability and qualitative analyses of cognitive impairment. *European neurology*, *36*, 378–384. http://dx.doi.org/10.1159/000117297

Carretti, B., Cornoldi, C., & Pelegrina, S. L. (2007). Which factors influence number updating in working memory? The effect of size distance and suppression. *British Journal of Psychology, 98*, 45–60. http://dx.doi.org/10.1348/000712606X104175

Del Missier, F., Hansson, P., Parker, A. M., Bruine de Bruin, W., Nilsson, L-G., & Mäntylä, T. (2017). Unraveling the aging skein: Disentangling sensory and cognitive predictors of age-related differences in decision making. *Journal of Behavioral Decision Making, 30,* 123–139. http://dx.doi.org/10.1002/bdm.1926

Del Missier, F., Mäntylä, T., & Bruine de Bruin, W. (2010). Executive functions in decision making: An individual differences approach. *Thinking & Reasoning, 16*, 69–97. http://dx.doi.org/10.1080/13546781003630117

Del Missier, F., Mäntylä, T., & Bruine de Bruin, W. (2012). Decision-making competence, executive functioning, and general cognitive abilities. *Journal of Behavioral Decision Making*, *25*, 331–351. http://dx.doi.org/10.1002/bdm.731

Del Missier, F., Mäntylä, T., Hansson, P., Bruine de Bruin, W., Parker, A. M., & Nilsson, L-G. (2013). The multifold relationship between memory and decision making: An individual-differences study. *Journal of Experimental Psychology: Learning, Memory & Cognition, 39*, 1344–1364. http://dx.doi.org/10.1037/a0032379

Finucane, M. L., Mertz, C. K., Slovic, P., & Schmidt, E. S. (2005). Task complexity and older adults' decision-making competence. *Psychology and Aging, 20,* 71–84. http://dx.doi.org/10.1037/0882-7974.20.1.71/

Finucane, M. L., Slovic, P., Hibbard, J. H., Peters, E., Mertz, C. K., & MacGregor, D. G. (2002). Aging and decision-making competence: An analysis of comprehension and consistency skills in older versus younger adults. *Journal of Behavioral Decision Making, 15,* 141–164. http://dx.doi.org/10.1002/bdm.407

Fisk, J. E, & Sharp, C. A. (2004). Age-related impairment in executive functioning: Updating, inhibition, shifting, and access. *Journal of Clinical Neuropsychology, 26*, 874–890. http://dx.doi.org/10.1080/13803390490510680

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). Mini Mental State: A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*, 189–198. http://dx.doi.org/10.1016/0022-3956(75)90026-6

Giovagnoli, A. R., Del Pesce, M., Mascheroni, S., Simoncelli, M., Laiacona, M., & Capitani, E. (1996). Trail making test: Normative values from 287 normal adult controls. *The Italian Journal of Neurological Sciences*, *17*, 305–309. http://dx.doi.org/10.1007/BF01997792

Hayes, A. F. (2013). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. Guilford Publications.

Heaton, R. K., Chelune, G. J., Talley, J. L., Kay, G. G., & Curtis, G. (1993). Wisconsin card sorting test manual: Revised and expanded. Odessa, TX: Psychological Assessment Resources.

Hess, T. M., Queen, T. L., & Ennis, G. E. (2013). Age and self-relevance effects on information search during decision making. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, 68, 703–711. http://dx.doi.org/10.1093/geronb/gbs108

Hess, M. T., Strough, J., & Löckenhoff, C. (2015). *Aging and decision making: Empirical and applied perspectives*. Academic Press

Horn, J. L., & Cattell, R. B. (1967). Age differences in fluid and crystallized intelligence. *Acta Psychologica, 26*, 107–129. http://dx.doi.org/10.1016/0001-6918(67)90011-X

Johnson, M. M. S. (1990). Age differences in decision making: A process methodology for examining strategic information processing. *Journal of Gerontology: Psychology Sciences, 45*, 75-78. http://dx.doi.org/10.1093/geronj/45.2.P75

Johnson, M. M. S. (1993). Thinking about strategies during, before, and after making a decision. *Psychology and Aging, 8*, 231–241. http://dx.doi.org/10.1037/0882-7974.8.2.231

Lecce, S., Ceccato, I., Rosi, A., Bianco, F., Bottiroli, S., & Cavallini, E. (2017). Theory of mind plasticity in aging: the role of baseline, verbal knowledge, and executive functions. *Neuropsychological Rehabilitation*, 1-16. http://dx.doi.org/10.1080/09602011.2017.1308871

Leventhal, E. A., Leventhal, H., Schaefer, P., & Easterling, D. (1993). Conservation of energy, uncertainty reduction, and swift utilization of medical care among the elderly. *The*

Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 48, 78–86. http://dx.doi.org/10.1093/geronj/ 48.2.P78

Löckenhoff, C. E., & Carstensen, L. L. (2007). Aging, emotion, and health-related decision strategies: Motivational manipulations can reduce age differences. *Psychology and Aging 22*, 134–146. http://dx.doi.org/10.1037/0882-7974.22.1.134.

MacKinnon, D. P. (2008). *Introduction to statistical mediation analysis*. London: Routledge.

MacKinnon, D. P., Krull, J. L., & Lockwood, C. M. (2000). Equivalence of the mediation, confounding and suppression effect. *Prevention science*, *1*, 173–181. http://dx.doi.org/10.1023/A:1026595011371

Mather, M. (2006). A review of decision-making processes: Weighing the risks and benefits of aging. In L. L. Carstensen, & C. R. Hartel (Eds.), *When I'm 64* (pp. 145–173). Washington D.C.: The National Academies Press.

Mayr, U., & Kliegl, R. (2000). Complex semantic processing in old age: Does it stay or does it go? *Psychology and Aging*, *15*, 29–34. http://dx.doi.org/10.1037/0882-7974.15.1.29

Mikels, J. A., Reed, A. E., & Simon, K. I. (2009). Older adults place lower value on choice relative to young Adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *64B*(4), 443–446. http://doi.org/10.1093/geronb/gbp021

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current directions in psychological science*, *21*, 8–14. http://doi.org/10.1177/0963721411429458

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*, 49–100. http://dx.doi.org/10.1006/1999.0734

Nelson, H. E. (1976). A modified card sorting test sensitive to frontal lobe defects. *Cortex, 12*, 313–324. http://dx.doi.org/10.1016/S0010-9452(76)80035-4

Park, D. C., Lautenschlager, G., Hedden, T., Davidson, N. S., Smith A.D., & Smith, P. K. (2002). Models of visuospatial and verbal memory across the adult life span. *Psychology and Aging, 17*, 299–320. http://dx.doi.org/10.1037/0882-7974.17.2.299

Parker, A. M., & Fischhoff, B. (2005). Decision-making competence: External validation through an individual-differences approach. *Journal of Behavioral Decision Making, 18,* 1–27. http://dx.doi.org/10.1002/bdm.481

Payne, J. W., Bettman, J. R., & Johnson, E. J. (1993). *The adaptive decision maker*. Cambridge University Press.

Peters, E., Hess, T. M., Västfjäll, D., & Auman, C. (2007). Adult age differences in dual information processes and their influence on judgments and decisions: A review. *Perspectives on Psychological Science*, *2*, 1–23. http://dx.doi.org/10.1111/j.1745-6916.2007.00025.x

Preacher, K. J., & Hayes, A. F., (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods, 40*, 879–889. http://dx.doi.org/10.3758/BRM.40.3.879

Queen, T. L., & Hess, T. M. (2010). Age differences in the effects of conscious and unconscious thought in decision making. *Psychology and Aging, 25*, 251–261. http://dx.doi.org/10.1037/a0018856.

Reed, A. E., Mikels, J. A., & Simon, K. I. (2008). Older adults prefer less choice than young adults. *Psychology and aging, 23*, 671–675. http://dx.doi.org/10.1037/a0012772.

Reitan, R. M., & Wolfson, D. (1985). *The Halstead Reitan neuropsychological test battery: Theory and clinical interpretation*. Tucson, AZ: Neuropsychology Press.

Rende, B., Ramsberger, G., & Miyake, A. (2000). Commonalities and differences in the working memory components underlying letter and category fluency tasks: a dual-task investigation. *Neuropsychology, 16*, 309–321. http://dx.doi.org/10.1037/0894-4105.16.3.309

Rönnlund, M., Nyberg L., Bäckman, L., & Nillson, L-G. (2005). Stability, growth, and decline in adult life span development of declarative memory: Cross-sectional and longitudinal data from a population-based study. *Psychology and Aging, 20,* 3–18. http://dx.doi.org/10.1037/0882-7974.20.1.3

Rypma, B., Prabhakaran, V., Desmond, E. J., & Gabrieli, E. D. J. (2001). Age differences in prefrontal cortical activity in working memory. *Psychology and Aging, 16*, 371–384. http://dx.doi.org/10.1037/0882-7974.16.3.371

Roca, M., Manes, F., Chade, A., Gleichgerrcht, E., Gershanik, O., Arévalo, G. G., ... & Duncan, J. (2012). The relationship between executive functions and fluid intelligence in Parkinson's disease. *Psychological medicine*, *42*(11), 2445–2452. http://dx.doi.org/10.1017/S0033291712000451

Salthouse, T. (2012). Consequences of age-related cognitive declines. *Annual Review of Psychology*, *63*, 201–226. http://dx.doi.org/10.1146/annurev-psych-120710-100328

Shao, Z., Janse, E., Visser, K., & Meyer, A. S. (2014). What do verbal fluency tasks measure? Predictors of verbal fluency performance in older adults. *Frontiers in psychology*, *5*. http://dx.doi.org/10.3389/fpsyg.2014.00772

Shrout, P. E., & Bolger, N. (2002). Mediation in experimental and nonexperimental studies: New procedures and recommendations. *Psychological methods*, *7*, 422–445. http://dx.doi.org/10.1037//1082-989X.7.4.422

Sobel, M. E. (1986). Some new results on indirect effects and their standard errors in covariance structure models. In N. Tuma (Ed.), *Sociological Methodology* (pp. 159–186). Washington, DC: American Psychology Association.

Strauss, E., Sherman, E. M. S., & Spreen, O. (2006). *Compendium of neuropsychological tests: Administration*, *norms*, *and commentary* (3rd ed.). Oxford: Oxford University Press.

Strough, J., Bruine de Bruin, W., & Peters, E. (2015). New perspectives for motivating better decisions in older adults. *Frontiers in psychology*, *6*. http://dx.doi.org/10.3389/fpsyg.2015.00783.

Thurstone, L. L. (1948). *Primary mental abilities*. University of Chicago Press, Chicago

Thurstone, T. G., & Thurstone, L. L. (1963). *Primary mental ability.* Chicago, IL: Science Research Associates.

Tombaugh, T. N., Kozak, J., & Rees, L. (1999). Normative data stratified by age and education for two measures of verbal fluency: FAS and animal naming. *Archives of clinical neuropsychology*, *14*, 167–177. https://doi.org/10.1016/S0887-6177(97)00095-4

Venneri A, Molinari MA, Pentore R, Cotticelli B, Nichelli P, & Caffarra P. (1993). Shortened Stroop color word test: Its application in Alzheimer's disease. *Advances in Human Biosciences, 87*, 81–82. http://dx.doi.org/10.1016/0197-4580(92)90135-K

Verhaeghen, P. (2003). Aging and vocabulary score: A meta-analysis. *Psychology and Aging*, *18*, 332–339. http://dx.doi.org/10.1037/0882-7974.18.2.332

von Helversen, B., & Mata, R. (2012). Losing a dime with a satisfied mind: Positive affect predicts less search in sequential decision making. *Psychology and Aging, 27*, 825–839. http://dx.doi.org/10.1037/a0027845

Wechsler D. (1981). Wechsler Adult Intelligence Scale – Revised (WAIS-R).

Footnotes

1 The whole Adult Decision Making Competence battery, including the Applying Decision Rules task, is available on-line (http://www.sjdm.org/dmidi/Adult_-_Decision_Making_Competence.html).

2 Our sample size was sufficient for detecting the relationship between age and the Applying Decision Rules, with effect size *d* = .77 estimated from a previous study (Del Missier et al., 2013), and with statistical power set at .95 and alpha at .05.

3 We provided intercorrelations, instead of coefficient alpha, due to having too few items.

4 The transformed score reflected $1/x$, where x represents the score obtained by the subject in the task.

5 The model for semantic knowledge revealed a suppression effect, while the other models revealed a mediation effect. Suppression and mediation effects are similar in the sense that both reflect the indirect effects of a third variable on a correlation (MacKinnon, Krull, & Lockwood, 2000; Preacher & Hayes, 2008). Suppression is said to occur when controlling for the third variable drives the correlation to be more positive or more negative. Mediation is said to occur when controlling for the third variable drives the correlation towards zero.

6 Because the three executive functioning measures (shifting, updating, and inhibition) were highly intercorrelated, we created a composite index score (Cronbach's alpha=.75) to reduce multicollinearity. The composite index score involved conversion of raw test scores to z-scores and averaging the z-scores. The bootstrapping analysis conducted with a composite index score of executive functioning revealed that the negative relationship between age group and Applying Decision Rules was still statistically explained by

working memory, 99.4% CI [-4.47, -.53], and verbal fluency, 99.4% CI [-4.02, -.07], and not by the composite executive functioning score, 99.4% CI [-14.39, .04]. The relationship between age group and Applying Decision Rules remained significant and negative (*B* = -36.82, *SE* = 3.32, $p < .001$), while the relationship between working memory and Applying Decision Rules was not significant (*B* = 3.32, *SE* = 1.42, *p* = .02) as well as the relationship between semantic memory fluency and Applying Decision Rules (*B* = .34, *SE* = .17, $p < .05$). The relationship between age group and working memory was not significant (*B* = -.66, *SE* = .24, *p* = .01) as well as between age group and verbal fluency (*B* = -4.23, *SE* = 1.93, *p* = .03). While, the negative relationship between age group and Applying Decision Rules remained negative and significant (*B* = -28.49, *SE* = 5.14, $p < .001$).

Table 1.

Descriptive statistics by Age Group.

		Younger *n* = 50	Older *n* = 50		
	Range	*M (SD)*	*M (SD)*	*t*(98)	*d*
Participants characteristics					
Age (years)	20-85	23.02 (3.08)	71.78 (6.13)	51.24**	10.05
Education (years)	8-21	15.64 (1.14)	14.78 (3.62)	1.68	0.32
Female Gender (%)	–	68%	70%	0.05 [a]	0.22[b]
MMSE	26-30	–	29.36 (0.98)	–	–
Cognitive measures					
Applying Decision Rules (%)	13.33-100	82.93 (12.29)	46.27 (19.73)	11.16**	2.23
Working memory	3-8	4.80 (1.12)	4.12 (1.22)	2.89**	0.59
Verbal fluency	23-72	48.68 (8.61)	44.02 (10.81)	2.38*	0.48
Semantic knowledge	37-50	44.00 (2.71)	46.88 (2.60)	5.42**	1.08
Complex EF	0-6	5.66 (0.98)	4.28 (1.71)	4.94**	1.00
Shifting	0.05-0.03	0.21 (0.04)	0.12 (0.04)	9.94**	2.25
Updating	1-22	14.74 (4.16)	9.18 (4.68)	6.28**	1.26
Inhibition	0.23-2.00	0.94 (0.34)	0.53 (0.21)	7.29**	1.46

Notes. *d* = Coehn's d; MMSE = Mini Mental State Examination
[a] Chi-square test value; [b] Phi correlation coefficient as a measure of effect size
** $p < .006$ (Bonferroni-corrected α); * $p < .05$

Table 2

Correlations Between Age Groups, Applying Decision Rules and Cognitive Abilities.

	1. Age	2. ADR	3. WM	4. VF	5. SK	6. C-EF	7. SHIF	8. UPD	9. INH
1. Age Group (Age)	—								
2. Applying Decision Rules (ADR)	-.77**	—							
3. Working Memory (WM)	-.29**	.46**	—						
4. Verbal Fluency (VF)	-.24**	.40**	.37**	—					
5. Semantic Knowledge (SK)	.47**	-.20*	.06	.13	—				
6. Complex EF (C-EF)	-.46**	.39**	.20	.11	-.19	—			
7. Shifting (SHIF)	-.73**	.65**	.41**	.36**	-.17	.42**	—		
8. Updating (UP)	-.56**	.56**	.49**	.34**	-.14	.35**	.53**	—	
9. Inhibition (IN)	-.60**	.58**	.31**	.25*	-.16	.21*	.60**	.36**	—

Notes. Correlations between Age Group and other variables are point-biserial, due to reflecting relationships between a dichotomous variable and a continuous variable. $^{**}p < .006$ (Bonferroni-corrected α); $^{*}p < .05$

Table 3

Single-Mediation Analyses of the Relationship Between Age Group and Applying Decision Rules Through Each Potential Mediator.

Potential mediator	Path A from Age Group to potential mediator		Path B from potential mediator to Applying Decision Rules		Path C from Age Group to Applying Decision Rules [a]		Path C' from Age Group to Applying Decision Rules [b]	
	B (SE)	*t*	*B (SE)*	*t*	*B (SE)*	*t*	*B (SE)*	Bootstrap 99.4% CI
Working memory	-0.68 (.23)	-2.90*	5.61 (1.31)	4.31**	-32.85 (3.15)	-10.43**	-3.81 (1.33)	-6.86, -1.51 [c]
Verbal fluency	-4.66 (1.96)	-2.39*	0.58 (.16)	3.64**	-33.95 (3.19)	-10.66**	-2.72 (1.41)	-6.48, -0.66 [c]
Semantic knowledge	2.88 (.53)	5.43**	1.71 (.60)	2.84**	-41.60 (3.62)	-11.50**	4.94 (1.79)	2.14, 9.30 [c]
Complex EF	-1.38 (.28)	-4.94**	1.09 (.92)	0.92	-35.16 (3.68)	-9.57**	-1.51 (1.97)	-5.92, 1.96
Shifting	-0.08 (.01)	-9.94**	95.32 (37.56)	2.54*	-28.52 (4.53)	-6.29**	-8.16 (3.62)	-15.71, -1.46 [c]
Updating	-5.56 (.89)	-6.28**	1.08 (.36)	3.01**	-30.64 (3.74)	-8.20**	-6.02 (2.21)	-10.93, -2.12 [c]
Inhibition	-0.42 (.06)	-7.30**	14.60 (5.79)	2.52*	-30.78 (4.02)	-7.66**	-6.02 (2.12)	-10.39, -2.09 [c]

Notes. Figure 1 shows the graphic representation of the single-mediation model for each potential mediator. *B* = unstandardized regression coefficient; *SE* = standard error of unstandardized regression coefficient.

[a] Direct effect between Age group and Applying Decision Rules.

[b] Indirect effect between Age group and Applying Decision Rules controlling for each mediator.

[c] Confidence interval does not include zero, indicating significant mediation.

** $p < .006$ (Bonferroni-corrected α); * $p < .05$

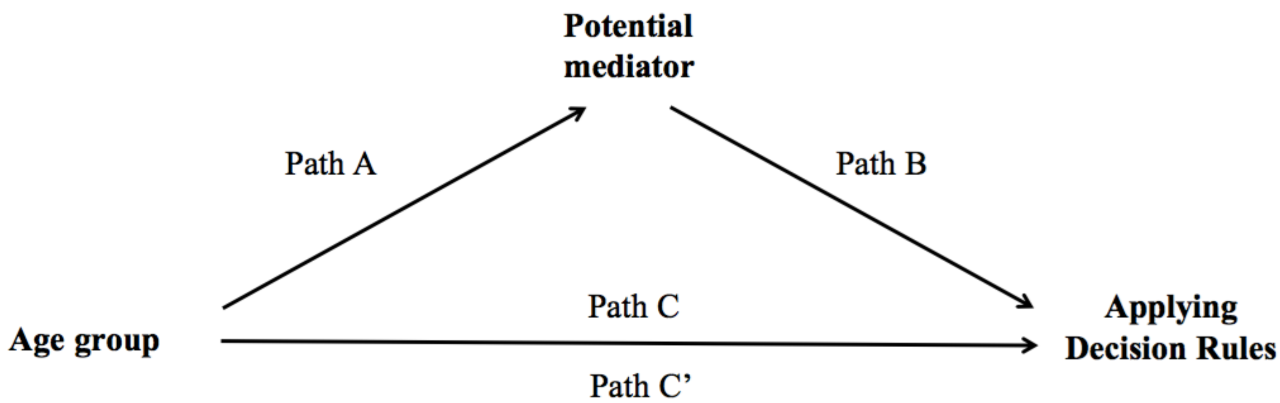

Figure 1. Graphic representation of single-mediation model for each potential mediator. Path A represents the relationship between age group and the potential mediator. Path B represents the relationship between the potential mediator and Applying Decision Rules. Path C represents the total effect of Age Group on Applying Decision Rules. Path C' represents the direct effect between Age Group and performance on the Applying Decision Rules task while taking into account the potential mediator.

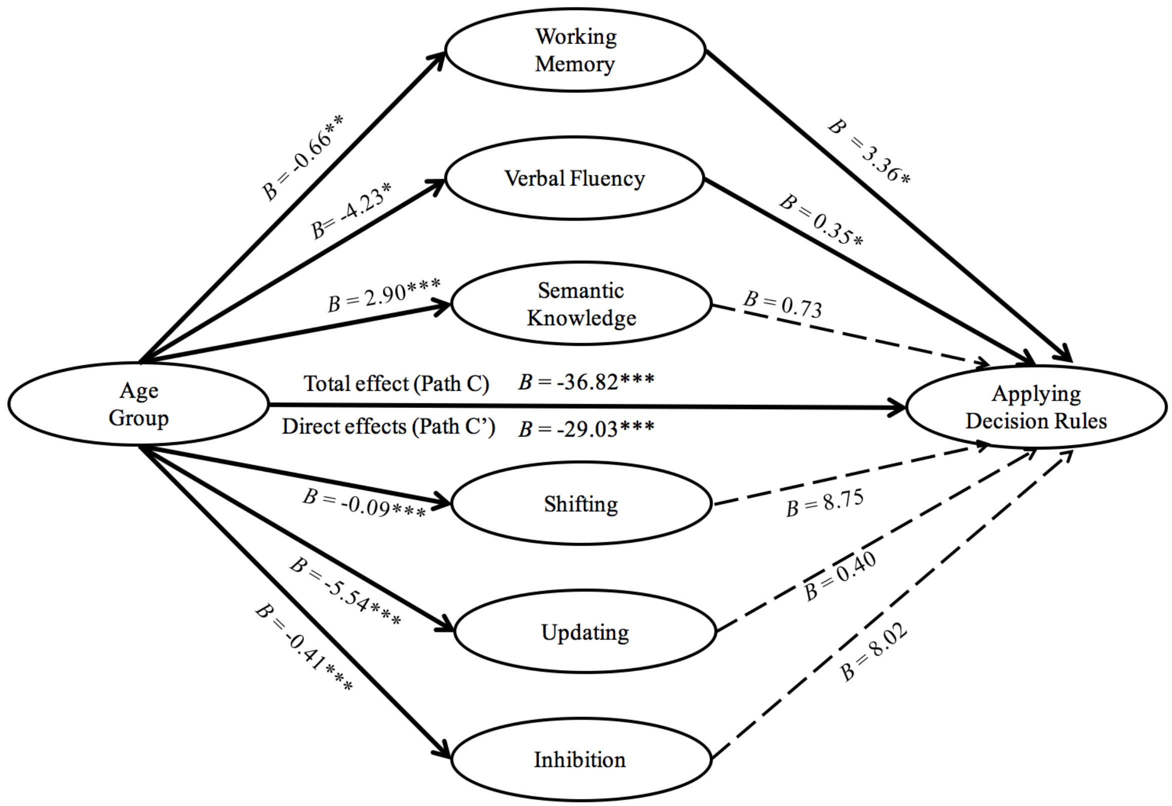

Figure 2. Graphic representation of multiple-mediation model across potential mediators that had been significant in single-mediation models. *B* values correspond to unstandardized regression coefficients. Path C represents the total effect of Age Group on Applying Decision Rules; Path C' represents the direct effect of Age Group on Applying Decision Rules while taking into account the potential mediators. Solid lines indicate statistically significant relationships, while dotted lines represent non-significant ones. After taking into account all cognitive measures, only working memory and verbal fluency significantly mediated the relationship between Age Groups and Applying Decision Rules.

$^{***}p < .001$; $^{**}p < .01$; $^{*}p < .05$