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Aging and Integration of Contingency Evidence in Causal Judgment

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Abstract

Age differences in causal judgment are consistently greater for preventative/negative relationships than for generative/positive relationships. We used a feature analytic procedure (Mandel & Lehman, 1998) to determine whether this effect might be due to differences in young and older adults' integration of contingency evidence during causal induction. To reduce the impact of age-related changes in learning/memory we presented contingency evidence for preventative, non-contingent, and generative relationships in summary form and to induce participants to integrate greater or lesser amounts of this evidence, we varied the meaningfulness of the causal context. Young adults showed greater flexibility in their integration processes than older adults. In an abstract causal context, there were no age differences in causal judgment or integration, but in meaningful contexts, young adults' judgments for preventative relationships were more accurate than older adults' and they assigned more weight to the contingency evidence confirming these relationships. These differences were mediated by age-related changes in processing speed. The decline in this basic cognitive resource may place boundaries on the amount or the type of evidence that older adults can integrate for causal judgment.

Keywords

Aging; causal judgment; integrative processing; working memory

People can acquire knowledge of the causal structure of the world through experience or description (Shanks, 1991). In the first case, direct observations of instances in which the presence or absence of a putative cause leads to the presence or absence of a target effect accumulate over an extended period of time. For example, one can learn whether a particular food causes an allergic reaction by observing over several months instances in which a reaction does or does not occur after consuming or not consuming the food. In the second case, this contingency evidence is provided in the form of a summary of the overall frequencies of the cause and effect event state combinations or from linguistic descriptions of causal scenarios. Thus, one can infer that a food is the putative cause of salmonella poisoning by reading in the newspaper that out of a group of people who consumed the food a large number became sick whereas out of a group of people who did not consume the food no one became sick. Learning and memory clearly play a larger role in the acquisition of contingency evidence through

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experience than through description; however, integrating (i.e., weighting and combining) this evidence plays an important role in inducing causal structure in both of these situations. Previous studies of aging and causal judgment have focused primarily on changes in older adults' ability to acquire contingency evidence through experience (e.g., Mutter, 2000; Mutter & Pliske, 1994, 1996; Mutter, Strain, & Plumlee 2007; Mutter & Williams, 2004). The current experiment explores the impact of age on the integration of contingency evidence acquired through description.

Contingency is defined statistically in terms of DP— the difference between the conditional probability of an effect (O) in the presence of a cause (C) and the conditional probability of an effect in the absence of the cause: $DP = P(O/C) - P(O/\sim C)$. In a generative or positive contingency, $P(O/C)$ is greater than $P(O/\sim C)$ so the effect is more likely to occur when the causal event occurs, whereas in a preventative or negative contingency, $P(O/\sim C)$ is greater than $P(O/C)$ so the effect is less likely to occur when the causal event occurs. In non-contingent relationships, these two probabilities are equal. These conditional probabilities are computed from the basic evidence needed to induce causal contingency, namely occurrences of the four possible combinations of the presence and absence of the putative cause and the effect. This evidence can be represented as the absolute frequencies of the event state combinations in Cells A – D of a 2×2 contingency table (see Figure 1). Studies investigating causal induction through experience often focus on the acquisition of this basic contingency evidence via associative learning processes (e.g., Mutter & Williams, 2004; Shanks & Dickinson, 1987; Wasserman & Castro, 2005), whereas those investigating causal induction via descriptive sources typically focus on differences in how the contingency evidence in these four cells is weighted and the rules that are used to combine this evidence for prediction and judgment (e.g., Levin, Wasserman, & Kao, 1993; Mandel & Lehman, 1998; Schustack & Sternberg, 1981; Shaklee & Mims, 1982; Wasserman, Dorner, & Kao, 1990; White, 2003).

A growing body of research shows that age has a detrimental effect on both non-causal and causal contingency judgment in experienced situations (e.g., Mutter, Haggblom, Plumlee, & Schirmer, 2007; Mutter, Plumlee, & DiCaro, under review; Mutter, Plumlee, & Strain, 2007; Mutter & Williams, 2004). These age differences are consistently larger for preventative/negative contingencies than for generative/positive contingencies and may be due to the greater cognitive resources required for the acquisition and retrieval of evidence that confirms a negative contingency. Findings by Mutter and Pliske (1996) provide some support for this idea. When young and older participants were required to estimate the frequencies of the event combinations in the four cells of the contingency table after a series of learning trials (high memory demand), age differences in estimation accuracy were larger for combinations that provided information about the probability of an effect in the absence of a putative cause (Cells C and D) than for combinations that provided information about the probability of an effect in the presence of this event (Cells A and B). In contrast, when participants were allowed to tally the frequencies of the four event combinations as they were presented (low memory demand), this age difference was not observed and both groups' tallies were more accurate for event combinations in Cells A and B than for those in Cells C and D. However, even with this support for acquiring the contingency evidence, age differences in causal judgment remained. Moreover, in both the estimating and tallying conditions, older adults adopted simple, less effective judgment strategies that used only part of the available contingency evidence. The modal judgment strategy used by older adults was the *Cell-A* rule, which identifies a relationship if the frequency in Cell A is either the greatest or the smallest of the four event combinations, whereas the modal judgment strategy used by young adults in both conditions was the *Sum-of-Diagonals* or ΔD rule, which involves integrating confirming and disconfirming contingency evidence $[(\text{Cell A} + \text{Cell D}) - (\text{Cell B} + \text{Cell C})]^1$.

Older adults use simple judgment strategies and make less accurate causal judgments even when support is provided for the acquisition of contingency evidence via experience (Mutter and Pliske, 1996). In line with this finding, other studies have shown that the ability to solve reasoning problems that involve combining multiple relations (i.e., matrices and transitive inference tasks) decreases with age, even when memory demands for the premises are reduced (e.g., Light, Zelinski, and Moore, 1982; Salthouse, 1992; Viscontas, Holyoak, and Knowlton, 2005). These studies suggest that the effect of age on reasoning is due to a decline in the cognitive resources that are necessary for coding, maintaining, and manipulating relational representations. A decline in these resources may also lead to changes in the amount or type of contingency evidence that older adults can integrate for causal judgment. To test this idea, we examined whether age differences in integration would be observed in a described situation when causal contingency evidence was provided in summary format.

We used the feature analytic procedure developed by Mandel and Lehman (1998) to examine young and older adults' integration of contingency evidence. The central idea behind this procedure is that judgment rules can be described by their features (i.e., combinations of the four cells of the contingency table) and are also exemplars of the features they comprise. It is therefore possible to construct rules that vary the weights of these features in order to examine their importance in the judgment process. For example, the sum-of-diagonals or ΔD rule ($\Delta D = w_A A - w_B B - w_C C + w_D D$) can be conceived as a weighted linear combination of the frequencies in the four cells of the contingency table where $w_A = w_B = w_C = w_D = 1$. Simpler judgment rules are special cases of the weighted ΔD rule; i.e., the Cell A rule weights conjunctions of the cause and effect more highly than all other event combinations ($w_A = 1$ and $w_B, w_C, \text{ and } w_D = 0$), while the A-minus-B rule compares the information in Cells A and B (i.e., $w_A = w_B = 1$ and $w_C = w_D = 0$). The viability or importance of a rule as a predictor of an individual's contingency judgment is defined as the correlation between that rule's output and the individual's actual judgment response.

Using the feature analysis procedure, we explored two related aspects of young and older adults' integration of contingency evidence in the described situation. First, we asked whether there might be differences in how the two groups weight the relative importance of the available evidence in the four cells of the contingency table. When young adults are asked to rank the importance of this evidence, they typically show a cell weight inequality effect (CWI) whereby $A > B \geq C > D$ (e.g., Mandel & Lehman, 1998; Kao & Wasserman, 1993; Levin, Wasserman, & Kao, 1993; Wasserman, Dornier, & Kao, 1990). Nevertheless, they process the less highly ranked evidence more inclusively in causal learning tasks when it is easily acquired and retrieved (e.g., Mutter & Pliske, 1996), when they are evaluating plausible hypotheses about the causal relationship between events (e.g., smoking – lung cancer; Fugelsang & Thompson, 2000; Mutter et al., 2007), and when task instructions induce them to intentionally focus on this information (Crocker, 1980; Maldonado, Jimenez, & Herrera, 2006). Thus, young adults direct additional cognitive resources to the “less important” contingency evidence in response to manipulations of the learning situation. However, older adults do not seem to show the same flexibility -- neither reducing memory demands for contingency evidence (Mutter & Pliske, 1996) nor presenting this evidence in a plausible causal context induces them to engage in more inclusive processing (Mutter et al., 2007). We were therefore interested in determining whether this age difference would occur when contingency evidence is both readily available and relevant to a meaningful causal hypothesis. To investigate this possibility, we examined the CWI effect for young and older adults in different causal contexts. Two of these contexts were meaningful (e.g., plant's blooming was caused, prevented, or unrelated to the application of

¹The information in Cells A and D provide evidence confirming a generative/positive contingency and disconfirming a preventative/negative contingency, whereas the information in Cells B and C provide evidence confirming a preventative/negative contingency and disconfirming a generative/positive contingency.

fertilizer) and one was abstract (e.g., Event O was caused, prevented, or unrelated to Event E). If young, but not older adults, integrate more of the available contingency evidence when evaluating meaningful causal hypotheses, there may be age differences in the CWI effect and in the accuracy of causal judgment in the meaningful contexts, but not in the abstract context.

Second, we asked whether there might be differences in the tests young and older adults use to evaluate causal hypotheses. Several researchers (Mandel and Lehman, 1998; Levin et al., 1993) have suggested that the CWI effect in young adults' causal judgment could be due to a tendency to weight *positive* tests more highly than *negative* tests (see Klayman & Ha, 1987 for further discussion of positive and negative hypothesis testing). In the 2×2 contingency table (see Figure 1), the evidence in Cell A is positive because both cause and effect are present, the evidence in Cells B and C is neutral because one of these events is present and the other is absent, and the evidence in Cell D is negative because both events are absent. Thus, a positive test (+test) bias leads to a higher weight for Cell A than Cell B and a higher weight for Cell C than Cell D. Mandel & Lehman have also shown that young adults weight *sufficiency* tests more highly than *necessity* tests. If a cause is sufficient to produce an outcome, the outcome rarely fails to occur when the cause occurs and event pairs in Cell B are infrequent relative to those in Cell A. However, if a cause is necessary to produce an outcome, the outcome rarely occurs when the cause is absent and event pairs in Cell C are infrequent relative to those in Cell A². A sufficiency test (Stest) bias therefore leads to a higher weight for Cell B than Cell C. We expected that older adults would resemble young adults in their preference for +testing and Stesting. However, because these tests require the evaluation of more of the available contingency evidence, older adults may weight them less highly than young adults, especially in the meaningful contexts. On the other hand, if young adults integrate less contingency evidence in the abstract context, age differences in these tests may be attenuated.

Finally, we explored the relationship between age-related changes in cognitive resources and integration of contingency evidence. If these changes contribute to a decline in older adults' performance, statistical control of processing speed and/or working memory executive function should reduce or eliminate age differences in measures of integration (CWI effect, +testing, sufficiency testing) and in the accuracy of causal judgment.

Method

Participants

Seventy-two young adults, with ages ranging from 18 to 26 years, were recruited from lower level psychology classes at Western Kentucky University and received course credit for their participation in this experiment. Seventy-two older adults, with ages ranging from 60 to 84 years, were recruited from the community and were paid a small stipend for their participation. None of the participants reported histories of neurological or psychiatric illness, none were taking medications known to affect cognitive functioning, and all were in good health for their age. Biographical and cognitive ability data for participants are presented in Table 1. Older adults were more highly educated than young adults and performed better on a test of verbal knowledge [i.e., Mill Hill Vocabulary (Wechsler, 1997)]. However, as is typical, their scores were lower than the young adults on tests of processing speed [i.e., WAIS-III Digit Symbol Substitution (Wechsler, 1997), Pattern Comparison, and Letter Comparison (Salthouse,

²The definition of sufficiency and necessity testing in causal judgment varies according to whether the hypothesized relationship is positive or negative (Mandel & Lehman, 1998). For a positive or a negative relationship, Cell A vs. Cell B = +Cause test/Stest and Cell C vs. Cell D = -Cause test/Ntest. For a hypothesized positive relationship, Cell A vs. Cell C = +Outcome test/Ntest and Cell B vs. Cell D = -Outcome test/Stest. For a hypothesized negative relationship, Cell A vs. Cell C = +Outcome test/Stest and Cell B vs. Cell D = -Outcome test/Ntest. Thus, +Cause and -Cause tests are always sufficiency and necessity tests, respectively, whereas +Outcome and -Outcome tests are sometimes sufficiency and sometimes necessity tests. The combination of a +test bias and a Stest bias should therefore produce the following viability differences for these tests: +Cause > +Outcome > -Outcome > -Cause.

1994)], and WM executive functioning [i.e., Reading Span and Computational Span (Salthouse & Babcock, 1991)].

Materials and Procedure

The feature analytic procedure developed by Mandel and Lehman (1998) was used in this experiment. Three sets of 12 causal judgment problems (4 preventative, 4 unrelated, 4 generative) were constructed with total frequencies of 10, 20, or 40 across the four cells of the 2×2 contingency table. For every problem, the frequency of one cell was larger than the frequencies of the other three cells by factors of 2.5 or 5.0 (e.g., $A = 5$, $B = 2$, $C = 2$, $D = 1$) and across problems, the mean frequency of each of the four cells was equivalent. This insured that across the problems, frequency values were distributed equally over the cells in the contingency table and that any differential influence of frequency would be due to differential weighting of this information by cell. The 36 causal judgment problems were presented in three different contexts. In the *Natural* context, the causal cue was whether or not a newly-developed fertilizer was applied and the outcome was whether or not a plant bloomed, in the *Social* context, the cue was whether or not an individual had a particular personality trait and the outcome was whether or not that individual initiated a conversation with a stranger, and in the *Abstract* context, the cue was whether or not Event E occurred and the outcome was whether or not Event O occurred. Twenty-four young and 24 older participants were randomly assigned to each context and the order of presentation of the four cell frequencies was counterbalanced within each Age $\times$ Context group.

Participants were told that the purpose of the experiment was to see how well people could judge the causal relationship between two events. For each context, they were instructed that they would receive information showing how the occurrence of 36 different events (i.e., fertilizers F1 – F36, personality traits T1 – T36, or events E1 – E36) influenced the occurrence of a target outcome (i.e., Lanyu plant blooming, talking to strangers, outcome O) and that they should use this information to determine the causal relationship between each event and the outcome. They were then shown the four cell frequencies for each problem in summary form, one cell at a time on the screen of a computer monitor. The frequency for each cell was presented in the form of a sentence (e.g., The “event” occurred and the “outcome” occurred.) with the frequency printed next to the sentence under the header *Instances out of “N”*, where N referred to the total number of instances (i.e., 10, 20, or 40). Participants were told to pay close attention to the frequency for each cell and to take as long as they liked to review this information because they would not be allowed to return to a previous screen. Immediately after seeing the last of the four cell frequencies for a problem, they were asked to estimate the strength and direction of the relationship between the events using a scale ranging from -3 (the “event” is a strong preventer of the “outcome”) through 0 (the “event” neither prevents nor causes the “outcome”) to $+3$ (the “event” is a strong cause of the “outcome”). The scale values of $+/-1$ and $+/-2$ were “weak” and “moderate”, respectively.

After the causal judgment task, participants completed the tests of verbal knowledge, processing speed, and WM executive functioning. They were then debriefed, given the opportunity to ask questions, and compensated for their participation.

Results

Separate analyses were conducted for causal judgment, the cell weight inequality effect, and +test and Stest biases. When age effects in these analyses were significant, we used a regression procedure recommended by Baron and Kenny (1986) to determine whether age-related variation in processing speed or working memory function mediated the effects. For a variable to mediate the effect of age, the following requirements must be met: (1) age must predict the mediating variable, (2) the mediating variable must predict the dependent variable, and (3) the

mediating variable must continue to predict the dependent variable after controlling for age. If these conditions are met, perfect mediation is observed when the relationship between age and the dependent variable is eliminated and partial mediation is observed when it is reduced. Alpha was set at $p \leq .05$ for initial tests and at $p \leq .01$ for follow-up tests to limit family-wise error.

Causal Judgments

Causal judgments for preventative, non-contingent, and generative problems were divided by three to convert them to a scale ranging from -1 (i.e., strong preventer) to $+1$ (i.e., strong cause). Mean judgments for the three causal contingencies are displayed in Table 2. The data for each contingency were submitted to regression analysis using orthogonal contrasts to represent the effects of Age, Natural vs. Social Context (NvS Context), Meaningful (Natural + Social) vs. Abstract Context (MvA Context), Age $\times$ NvS Context, and Age $\times$ MvA Context.

Positive Contingency—The age and context variables did not account for a significant amount of variance in the causal judgments for the positive contingencies, $R^2 = .04$, $F(5, 138) = 1.29$, $MSE = .06$.

Zero Contingency—The age and context variables accounted for a 8% of the variance in causal judgments for the zero contingencies which was significant, $F(5, 138) = 2.37$, $MSE = .02$. Further examination of the individual effects indicated that overall judgments were closer to zero for the meaningful context than for the abstract context, $B = -.02$, $SE B = .01$, $\beta = -.18$, $t(138) = -2.21$, but no other effects were significant.

Preventative Contingency—The age and context variables accounted for 27% of the variance in the causal judgments for the negative contingencies, $F(5, 138) = 10.21$, $MSE = .06$. Young adults' preventative judgments were more negative than older adults' judgments, $B = -.07$, $SE B = .02$, $\beta = -.30$, $t(138) = -4.18$. Judgments were more negative in the natural, than the social context, $B = -.11$, $SE B = .02$, $\beta = -.34$, $t(138) = -4.64$, but this effect did not vary with age, $B = .00$, $SE B = .02$, $\beta = .00$, $t(138) < 1.00$. Judgments were also more negative in the meaningful context than the abstract context, $B = -.04$, $SE B = .01$, $\beta = -.19$, $t(138) = -2.67$, and this effect did vary with age, $B = -.03$, $SE B = .01$, $\beta = -.16$, $t(138) = -2.22$.

To further explore the Age $\times$ MvA Context interaction in preventative causal judgment, the effect of context was tested separately for young and older adults and the effect of age was tested separately for the meaningful and abstract contexts. Young adults' judgments were more negative in the meaningful context than in the abstract context, $B = -.07$, $SE B = .02$, $\beta = -.36$, $t(70) = -3.22$. In contrast, context had little effect on older adults' judgments, $B = -.01$, $SE B = .02$, $\beta = -.04$, $t(70) = -.30$. Moreover, young adults' judgments were more negative than older adults' judgments in the meaningful context, $B = -.11$, $SE B = .03$, $\beta = -.42$, $t(94) = -4.47$, but judgments for the two groups did not differ in the abstract context, $B = -.02$, $SE B = .04$, $\beta = -.08$, $t(46) = -.54$.

Processing speed mediated the effect of age on preventative causal judgment in the meaningful context, but working memory did not mediate this effect. The results of the mediation analyses are shown in Table 3. Young adults had higher processing speed scores than older adults and higher processing speeds were associated with more negative preventative judgments. When processing speed was entered with age, it continued to be a significant predictor of judgment performance, whereas age did not. Although young adults had higher working memory scores than older adults and higher working memory scores were associated with more negative preventative judgments, when both of these variables were entered as predictors for judgment, age continued to predict performance, but WM did not.

Cell Weight Inequality Effect

To obtain viabilities for each cell of the 2×2 contingency table, we computed the correlations between the four cell frequencies and each participant's causal judgment. This produced one r value for each cell for each participant. We then obtained the viabilities for each cell by Fisher-transforming these r values to z -scores. The absolute value of the viability score indicates the weight assigned to a particular cell in causal judgment while the sign of the score indicates how the information in that cell affected the direction of causal judgment. The signed cell viabilities for the natural, social, and abstract contexts are shown in Table 4³. Because the effect of age on preventative causal judgment varied for meaningful and abstract contexts, but not natural and social contexts, we focus solely on the MvA Context contrast in all subsequent analyses of context effects. To answer the question of whether young and older adults' cell viability data showed the CWI effect (i.e., Cell A > Cell B $\geq$ Cell C > Cell D) in both contexts, we conducted a 2 (MvA Context) $\times$ 4 (Cell) ANOVA with orthogonal contrasts (Cell A vs. Cell B, Cell B vs. Cell C, and Cell C vs. Cell D) on unsigned viability scores for each group. For young adults, viabilities were higher for Cell A than for Cell B, $F(1, 70) = 42.47$, $MSE = .07$, $\eta^2 = .38$, and for Cell C than for Cell D, $F(1, 70) = 29.42$, $MSE = .08$, $\eta^2 = .30$, but they did not differ for Cell B and Cell C, $F(1, 70) = 1.99$, $MSE = .09$, $\eta^2 = .03$. In addition, their viabilities were higher in the meaningful context than in the abstract context for all four cells [MvA Context, $F(1, 70) = 7.87$, $MSE = .01$, $\eta^2 = .10$; MvA Context $\times$ Cell, $F(1, 70) = 1.22$, $MSE = .04$, $\eta^2 = .01$].

For older adults, Cell A viabilities were higher than Cell B viabilities, $F(1, 70) = 41.34$, $MSE = .10$, $\eta^2 = .37$, Cell C viabilities were higher than Cell D viabilities, $F(1, 70) = 16.17$, $MSE = .09$, $\eta^2 = .19$, and Cell B and Cell C viabilities did not differ, $F(1, 70) = 1.01$, $MSE = .09$, $\eta^2 = .01$. Thus, like young adults, older adults showed a clear CWI effect. Context had no effect on older adults' overall cell viabilities, $F(1, 70) < 1.00$, $MSE = .01$, but their individual cell viabilities differed in the meaningful and abstract contexts, $F(3, 210) = 3.23$, $MSE = .05$, $\eta^2 = .04$. Viabilities for Cell A, $F(1, 70) = 4.21$, $MSE = .06$, $\eta^2 = .06$, $p \leq .04$, and Cell D, $F(1, 70) = 4.03$, $MSE = .03$, $\eta^2 = .06$, $p \leq .05$, were marginally higher in the meaningful context, whereas viabilities for Cell B, $F(1, 70) = 1.94$, $MSE = .06$, $\eta^2 = .03$, and Cell C, $F(1, 70) < 1.00$, $MSE = .04$, $\eta^2 = .00$, did not vary with context.

To compare young and older adults' cell viabilities in meaningful and abstract contexts and to determine whether observed age differences were mediated by processing speed or WM, signed viability scores for each cell in each context were regressed on age. Positive viabilities for a cell indicate that participants judged the causal relationship to be more positive when the frequency of the event pairs in that cell was high and negative viabilities for a cell indicate that they judged the causal relationship to be more negative when the frequency of event pairs in that cell was high. In the meaningful context, young adults' cell viabilities were more positive for Cell A and more negative for Cell B than those of older adults. Similar age effects were present for Cells D and C, respectively, though these differences were smaller and only marginally significant [Cell A, $B = .06$, $SE B = .02$, $\beta = .28$, $t(94) = 2.88$; Cell B, $B = -.08$, $SE B = .02$, $\beta = -.37$, $t(94) = -3.84$; Cell C, $B = -.04$, $SE B = .02$, $\beta = -.22$, $t(94) = -2.17$; Cell D, $B = .05$, $SE B = .02$, $\beta = .23$, $t(94) = 2.30$. In contrast, in the abstract context, age had no effect on viability for any of the four cells [Cell A, $B = .05$, $SE B = .03$, $\beta = .22$, $t(46) = 1.51$; Cell B, $B = -.07$, $SE B = .04$, $\beta = -.27$, $t(46) = -1.87$; Cell C, $B = -.02$, $SE B = .03$, $\beta = -.09$, $t(46) = -.62$; Cell D, $B = -.02$, $SE B = .02$, $\beta = -.10$, $t(46) = -.68$]. Thus, the frequency of the event

³The Fisher transformation is used to increase the normality of the distribution of the correlations. Mandel and Lehman (1998) used unsigned viability scores in their analyses for young adults. We therefore used unsigned viabilities when comparing scores within an age group. However, we elected to analyze signed scores when comparing age groups because they revealed interesting differences in the impact of the contingency evidence on young and older adults' judgment.

pairs in the cells had a greater influence on younger than older adults' judgments in the meaningful context, but not in the abstract context.

Processing speed mediated age differences in cell viability in the meaningful context, but working memory did not mediate these differences. The results of the mediation analyses are shown in Table 5. As noted above, age was a strong predictor for both processing speed and WM scores (see Table 3). Processing speed predicted Cell A, Cell B, and Cell C viability scores but did not predict Cell D scores. Working memory predicted viability scores for all four cells. When processing speed was entered with age as a predictor for Cell A viabilities, it continued to have a strong effect on these scores, whereas the age effect was no longer significant. The same outcome was observed for Cells B and C. Thus, processing speed mediated age differences in viabilities for Cells A, B, and C, but failed to meet the requirements for mediation of these differences in Cell D. When WM was entered with age as a predictor for Cell A viabilities, age continued to predict these scores, whereas WM was no longer a significant predictor. For Cell B, both age and working memory were significant predictors of cell viability, while for Cells C and D neither variable was a significant predictor of viability. Thus, working memory did not meet the requirements for mediation of age differences in cell viability.

+Test and Stest Biases

To determine whether young and older adults showed +test and Stest biases (see Figure 1) in the meaningful and abstract contexts, we obtained correlations between the output of four special cases of the weighted ΔD rule ($\Delta D = w_A A - w_B B - w_C C + w_D D$) and causal judgment for each participant. In this formula, A, B, C, and D were the cell frequencies for a problem and the weights were as follows: +Cause test, $w_A = w_B = 1$ and $w_C = w_D = 0$, -Cause test, $w_A = w_B = 0$ and $w_C = w_D = 1$, +Outcome test, $w_A = w_C = 1$ and $w_B = w_D = 0$, -Outcome test, $w_A = w_C = 0$ and $w_B = w_D = 1$. Viabilities were obtained as before and the mean viabilities for each context are displayed in Table 6. As with cell viability scores, the absolute value of a test's viability score indicates the weight assigned to that particular test in causal judgment while the sign indicates how the test affected the direction of causal judgment. Because either a +test bias or an Stest bias could cause viabilities for the +Cause test to exceed those of the -Cause test, we examined the +test bias using a conservative 2 (MvA Context) $\times$ 2(+Test) mixed factorial ANOVA for +Outcome and -Outcome test viabilities (cf., Mandel & Lehman, 1998). The Stest bias was examined by two, 2(MvA Context) $\times$ 2(Stest) mixed factorial ANOVAs, one comparing +Cause and +Outcome test viabilities and one comparing -Cause and -Outcome test viabilities. As before, we used unsigned viability scores for tests conducted within an age group and signed viability scores for tests of age effects.

The analysis of the +test bias for young adults showed that overall viability scores were higher in the meaningful context than in the abstract context, $F(1, 70) = 4.08$, $MSE = .04$, $\eta^2 = .06$. Viabilities were also higher for the +Outcome test, (i.e., A vs. C), than for the -Outcome test, (i.e., B vs. D), $F(1, 70) = 28.99$, $MSE = .04$, $\eta^2 = .29$, and this +test bias was greater in the meaningful context than in the abstract context, $F(1, 70) = 3.95$, $\eta^2 = .05$. The analysis of +test bias for older adults revealed no effect of context on overall viability scores, $F(1, 70) < 1.00$, $MSE = .04$. Viabilities were higher for the +Outcome test than the -Outcome test, $F(1, 70) = 24.70$, $MSE = .03$, $\eta^2 = .26$, and this +test bias did not vary with context, $F(1, 70) = 1.24$, $\eta^2 = .02$.

The presence of an Stest bias in the meaningful and abstract contexts was first examined by comparing unsigned viabilities for the +Cause (i.e., A vs. B) and +Outcome (i.e., A vs. C) tests. For young adults, overall viability was greater in the meaningful than the abstract context, $F(1, 70) = 11.70$, $MSE = .10$, $\eta^2 = .14$, the viability of the +Cause test was greater than that of the +Outcome test, $F(1, 46) = 12.37$, $MSE = .04$, $\eta^2 = .15$, and this was the case for both contexts,

$F(1, 70) = 1.78, \eta^2 = .02$. Analysis of the –Cause (i.e., C vs. D) and –Outcome (i.e., B vs. D) tests for young adults revealed that overall viability did not vary by context, $F(1, 70) < 1.00$, $MSE = .03$, viabilities for the –Cause test were higher than those for the –Outcome test, $F(1, 70) = 6.73, MSE = .02, \eta^2 = .09$, and this was again the case for both contexts, $F(1, 70) < 1.00$. Thus, young adults' showed an Stest bias in both contexts. In contrast, older adults' viabilities did not increase in the meaningful context and they showed little evidence of an Stest bias with either +Cause and +Outcome tests [MvsA Context, $F(1, 70) = 2.52, MSE = .09, \eta^2 = .03$, Test, $F(1, 70) = 1.64, MSE = .03, \eta^2 = .02$, MvA Context $\times$ Test, $F(1, 70) < 1.00$] or –Cause and –Outcome tests [MvA Context, $F(1, 70) = 1.04, MSE = .02, \eta^2 = .01$, Test, $F(1, 70) = 2.06, MSE = .02, \eta^2 = .03$, MvA Context $\times$ Test, $F(1, 70) = 1.41, \eta^2 = .02$].

Regression analyses were used to examine age differences in signed viabilities for the individual +Cause, –Cause, +Outcome, and –Outcome tests in the meaningful and abstract contexts and to assess whether processing speed or working memory mediated the observed differences. The results of these analyses are shown in Table 7. In the meaningful context, young adults' viabilities were more positive than older adults' viabilities for the +Cause and +Outcome tests and were more negative for the –Cause and –Outcome tests. Moreover, both processing speed and working memory predicted viabilities for all four tests in the meaningful context. When processing speed was entered with age as a predictor for the +Cause test viabilities, it continued to have a strong effect on these scores, whereas the age effect was no longer significant. This was also the case for the + Outcome test viabilities, but not for the –Cause test or –Outcome test viabilities. Thus, processing speed mediated the age effect for the +Cause and +Outcome tests, but not the –Cause and –Outcome tests. Working memory did not mediate age differences for any of these tests in this context.

In the abstract context, young adults' viabilities were more positive than older adults' viabilities for the +Cause test, but this difference was only marginally significant; viabilities for the two groups did not differ for the remaining tests [+Cause, $B = .11, SE B = .05, \beta = .30, t(46) = 2.13$; –Cause, $B = -.00, SE B = .03, \beta = -.01, t(46) = -.04$; +Outcome, $B = .05, SE B = .04, \beta = .20, t(46) = 1.39$; –Outcome, $B = -.05, SE B = .04, \beta = -.19, t(46) = -1.29$].

To summarize, age effects in causal judgments for generative and non-contingent relationships were small or non-existent for both the meaningful and the abstract context. In contrast, both age and context affected judgments for the preventative relationships. Older adults' judgments for this causal relationship were much less accurate than those of young adults in the meaningful context, but did not differ from young adults' judgments in the abstract context. Moreover, young adults' preventative judgments were much more accurate in the meaningful context than in the abstract context, but the accuracy of older adults' judgments did not vary for the two contexts. Both age groups showed a CWI effect ($A > B \geq C > D$). For young adults, the viabilities of all four cells were higher in the meaningful context than in the abstract context, whereas for older adults, viabilities were only marginally higher for Cells A and D in the meaningful context and did not differ for Cells B and C. Likewise, in the meaningful context, young adults gave greater weight to the contingency evidence in all four cells than did older adults, though this effect was greater for Cells A and B than for Cells C and D. In contrast, cell viabilities for the two groups did not differ in the abstract context. Young adults showed both a +test bias (+Outcome vs. –Outcome) and an Stest bias (+Cause vs. +Outcome and –Cause vs. –Outcome). Their +test bias was stronger in the meaningful context than in the abstract context, whereas their Stest bias did not vary for the two contexts. Older adults also showed a +test bias, but they did not show an Stest bias and in contrast to young adults, their +test bias did not increase in the meaningful context. Consistent with these findings for the +test and Stest biases, young adults' viabilities were higher than those of older adults for +Cause (A vs. B), –Cause (C vs. D), +Outcome (A vs. C), and –Outcome (B vs. D) tests in the meaningful context, but in the abstract context they were only marginally higher for the +Cause test and

did not differ for the other tests. Finally, the age differences in preventative causal judgment, cell viability, and the +Cause and +Outcome tests were mediated by processing speed, but not by WM functioning.

Discussion

The purpose of this experiment was to determine whether integration of contingency evidence acquired through summary description changes with age. The results clearly show that there are age differences in integration of this evidence and that these differences are greater in meaningful than in abstract causal contexts. The causal judgments of older adults were less accurate than those of young adults for preventative relationships in the meaningful context (i.e., natural + social), but not in the abstract context. In addition, while young adults' preventative causal judgments were more accurate in the meaningful context than in the abstract context, context had no effect on older adults' judgment accuracy. This pattern of age and context effects in judgment accuracy was consistent with the integration findings. Specifically, young adults gave greater weight to the contingency evidence than older adults in the meaningful, but not the abstract context and young, but not older adults' integration of evidence confirming a preventative causal relationship (Cells B and C) increased in the meaningful context relative to the abstract context. These findings suggest that whereas young adults integrate greater or lesser amounts of contingency evidence in response to contextual variables, older adults do not show the same degree of flexibility in their integration processes. This is particularly detrimental to their causal judgments for preventative relationships.

Before turning to a discussion of these age differences in integration and causal judgment, it is important to note that young and older adults' general beliefs concerning the differential importance of the evidence in the four cells of the contingency table were similar. Consistent with the CWI effects shown in prior research (c.f., Mandel and Lehman, 1998; Wasserman et al., 1990), both young and older adults in this study considered the evidence in Cell A to be the most important for their causal judgments, followed by the evidence in Cells B, C, and D. Mandel and Lehman suggested that the CWI effect reflects a primary +test bias (A vs. B, which leads to greater weight for the positive evidence in Cell A than the negative evidence in Cell D, combined with a secondary Stest bias, which leads to greater weight for the neutral evidence in Cell B than that in Cell C. Young adults showed a primary +test bias and a secondary Stest bias, while older adults showed a +test bias and no Stest bias. Thus, the tendency to conduct positive rather than negative tests in causal hypothesis testing appears to be preserved across the lifespan. However, older adults apparently did not have a strong tendency to conduct sufficiency tests rather than necessity tests. This outcome may be related to the finding that older adults most often use a Cell A rule, which involves comparing the information in Cell A with that in the other cells (Mutter & Pliske, 1996). Consistent with this idea, older adults' viabilities for Stests involving Cell A were equally high [i.e., +Outcome (A vs. B) = -Outcome (A vs. C)], whereas their viabilities for Stests involving only Cells B, C, or D were equally low [i.e., -Cause (C vs. D) = -Outcome (B vs. D)].

Although general beliefs about the differential importance of contingency evidence (i.e., the CWI effect) were similar for the two age groups, young adults clearly showed greater flexibility in the integration of this evidence than older adults. When the causal reasoning scenario was abstract and relatively meaningless, neither young nor older adults assigned much weight to evidence confirming a preventative relationship, yet when the causal scenario was meaningful, young adults assigned greater weight to this evidence and to hypothesis tests involving comparisons of this evidence. This resulted in an improvement in their judgment accuracy. Thus, whether contingency evidence is presented via experience or summary description, young adults adjust how extensively they integrate the available contingency evidence based

on the requirements of the judgment task (c.f., Crocker, 1982; Fugelsang & Thompson, 2000; Maldonado et al., 2006; Mutter et al., 2007).

Unlike young adults, older adults did not process the descriptive contingency evidence more extensively in the meaningful causal context. This outcome appears to be at odds with findings showing that older adults often benefit from familiar or meaningful material in other task domains. For example, age differences in memory tend to be smaller when material is related to existing knowledge than when it is unrelated or irrelevant to this knowledge (for a review, see Hess, 1990). Consistent with this finding, research has shown that belief-confirming contingency evidence is over-represented in older adults' memory relative to belief-disconfirming evidence when this evidence is presented via experience, (e.g., Mutter & Pliske, 1994; Mutter et al., 2007). However, the memory advantage for belief-confirming evidence is not associated with a beneficial effect in causal judgment, suggesting that older adults do not fully evaluate and integrate the evidence even when it is relevant to their beliefs and readily available in memory (Mutter et al., 2007). The present findings provide an important extension to this earlier research by showing that this is also the case when contingency evidence is presented by summary description in a meaningful causal scenario.

When memory demands are reduced, older adults continue to have difficulty with judgment and reasoning tasks that involve combining multiple relations (e.g., Light et al., 1982; Mutter & Pliske, 1996, Mutter et al., 2007, Salthouse, 1992; Viscontas et al., 2005). This effect of "relational complexity" may be due to an age-related decline in the cognitive resources needed to process relational representations (e.g., Viscontas et al., 2005). In particular, a decline in older adults' rate of information processing may reduce the number of distinct representations they can maintain and process in working memory (Salthouse, 1992). The finding that age differences in preventative causal judgment, in the weights assigned to the four cells of the contingency table, and in the various hypothesis tests comparing the contingency evidence in these cells were all mediated by processing speed suggests that changes in this basic cognitive resource may limit older adults' ability to evaluate and integrate contingency evidence in causal reasoning.

A reduction in cognitive resources could place boundaries on the *amount* of contingency evidence that older adults can integrate into a causal judgment. If so, it is not irrational for them to direct their attention to the evidence they believe to be most important and ignore the evidence they believe to be least important. Thus, a compensatory attentional strategy directed by general causal beliefs concerning the differentially greater importance of contingency evidence confirming a generative relationship offers one explanation for why age differences are consistently smaller for generative than preventative causal judgments (e.g., Mutter et al., 2006, 2007; Mutter, DeCaro, & Plumlee, 2009; Mutter & Williams, 2004). By this view, older adults should be able to direct their attention to evidence confirming a preventative relationship when they believe this evidence is the most important for their judgment. This idea was not tested in the present experiment, but other research (i.e., Mutter et al., 2007) shows that when older adults have strong pre-existing beliefs that events are negatively related, their memory for the confirming contingency evidence and their contingency estimates do shift in the direction of this belief.

However, even when older adults direct their attention to evidence confirming preventative causal relationships, their judgments for these relationships continue to be much less accurate than those of young adults (Mutter et al., 2007). This raises the possibility that age-related changes in cognitive resources limit the *type* of contingency evidence that older adults can represent for causal judgment. Maldonado et al. (2006) recently demonstrated that young adults acquire causal relationships relatively automatically when both cue and outcome are concurrently present (i.e., Cell A), but focal attention is required when one or both of these

events are absent (i.e., Cells B, C, D). Thus, generative causal judgments may have been less sensitive to manipulations of age and context because representing the confirming evidence for these judgments is not particularly demanding, whereas preventative causal judgments may have been more sensitive because representing the evidence confirming these relationships requires additional cognitive resources. The summary format used in the present study should have reduced representational requirements for the contingency evidence, but we cannot rule out the possibility that even with this support, it is more difficult to code and maintain in working memory the knowledge that a cue or outcome is absent. By this view, in the meaningful causal context young adults devoted additional resources to representing the contingency evidence confirming a preventative relationship, whereas in the abstract causal context they did not. As a result, their preventative causal judgments were more accurate in the meaningful context. Older adults were less able to marshal the necessary resources for representing the contingency evidence confirming the preventative relationships. Consequently, their preventative causal judgments were inaccurate in both contexts⁴.

To conclude, the results of this study provide another piece to the puzzle of why there are only small or no age differences in contingency and causal judgments for positive/generative relationships while large age differences are consistently observed for negative/preventative relationships. These differences do not appear to be due to age-related changes in general beliefs concerning the relative importance of contingency evidence confirming generative and preventative relationships, but rather to changes in basic cognitive resources that affect the representation and integration of this evidence. In particular, these changes may limit the amount of contingency evidence older adults can integrate and/or their ability to code and represent evidence in which the cue or outcome event is absent. Additional research is needed to determine which of these factors is most relevant to the age differences observed in contingency and causal judgment.

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⁴Notably, the composite measure of processing speed was also related to preventative causal judgment and integration performance within the older adult group. Higher scores on the speed composite were associated with lower (more accurate) causal judgments for the preventative contingency, $r = -.26, p = .03$. Likewise, higher composite speed scores were associated with higher viabilities for Cell B, $r = -.27, p = .02$, and Cell C, $r = -.29, p = .01$, but not Cell A, $r = .08, p = .49$, or Cell D, $r = -.03, p = .49$. In contrast to these results for older adults, speed was not related to causal judgment or cell viability for young adults [all correlations, $-.16 \leq r \leq .07$]. Thus, older adults with the least decline in this basic cognitive resource tended to make more accurate preventative causal judgments and to assign greater weight to the contingency evidence supporting these judgments (i.e., Cells B and C).

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		EFFECT		
		O	~O	
CAUSE	C	Cell A +, + Confirmation	Cell B +, - Insufficiency	+Ctest/Stest
	~C	Cell C -, + Nonnecessity	Cell D -, - Confirmation	-Ctest/Ntest
		+Otest/Ntest	-Otest/Stest	

Figure 1.

A 2×2 contingency table for a hypothesized generative causal relationship. The variables in the cells of the table represent the frequencies of co-occurrence for the two states of a candidate cause and effect.

Table 1

Participant Characteristics

	Context					
	Natural			Social		
	Young	Older		Young	Older	Abstract
<i>N</i>	24	24		24	24	24
Age	19.83 (1.81)	69.79 (1.43)		19.92 (1.77)	71.75 (1.44)	19.42 (1.70)
Education (yrs.)	13.04 (1.16)	15.38 (3.57)		13.42 (1.47)	14.75 (2.62)	12.83 (1.17)
<i>Working Memory Span</i>						
Reading Span*	2.50 (1.10)	2.09 (0.90)		2.71 (1.37)	1.58 (0.88)	2.75 (1.07)
Computational Span*	4.58 (1.69)	3.54 (2.10)		4.08 (2.02)	2.58 (1.95)	4.67 (1.66)
<i>Processing Speed</i>						
Pattern Comparison*	56.58 (8.21)	42.67 (7.80)		52.92 (8.10)	38.37 (6.40)	56.96 (8.11)
Letter Comparison*	43.00 (6.14)	31.38 (5.78)		40.50 (7.77)	29.25 (7.07)	43.75 (7.69)
WAIS-III Digit Symbol*	84.12 (10.14)	61.21 (14.77)		81.38 (12.40)	53.83 (16.10)	80.67 (10.25)
<i>Verbal Knowledge</i>						
Mill Hill Vocabulary*	30.33 (4.40)	39.67 (8.05)		30.12 (4.95)	35.71 (6.91)	29.04 (4.49)

Note. Table entries are means with standard deviation in parentheses. Reading Span and Computational Span (Salthouse & Babcock, 1991), Pattern and Letter Comparison (Salthouse, 1994), WAIS-III Digit Symbol (Wechsler, 1997), Mill Hill Vocabulary (Raven, Raven, & Court, 1989).

* Age, $p \leq .001$

Table 2

Mean Causal Judgments for Young and Older Participants

Context	Causal Relationship					
	Preventative			Non-contingent		
	<i>M</i>	<i>SE</i>		<i>M</i>	<i>SE</i>	<i>M</i>
Natural						
Young	-.40	.04		-.04	.02	.34
Older	-.16	.05		.04	.03	.20
Social						
Young	-.16	.04		.05	.02	.27
Older	.07	.05		.09	.04	.25
Meaningful (Natural + Social)						
Young	-.28	.03		.01	.02	.31
Older	-.04	.04		.06	.03	.23
<i>M</i>	-.16			.03		.27
Abstract						
Young	-.07	.07		.11	.04	.27
Older	-.02	.04		.09	.04	.18
<i>M</i>	-.04			.10		.23

Table 3
Mediation Analyses for Preventative Causal Judgments in the Meaningful Context (*N* = 96)

	Judgment			Speed			WM		
	<i>B</i>	<i>SE</i>	<i>B</i>	<i>SE</i>	<i>B</i>	<i>SE</i>	<i>B</i>	<i>SE</i>	<i>B</i>
Age	-.12	.03	-.42**	.07	.66	.07	.71**	.33	.08
Speed	-.14	.03	-.47**						.39**
WM	-.10	.03	-.31**						
Age with Speed	-.05	.04	-.17						
Speed with Age	-.11	.04	-.35**						
Age with WM	-.10	.03	-.35**						
WM with Age	-.06	.03	-.17						

**
p ≤ .01.

Table 4

Mean Signed Viabilities for Cell A, Cell B, Cell C, and Cell D by Context

Context	Cell A		Cell B		Cell C		Cell D	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Natural								
Young	.54	.03	-.28	.03	-.24	.04	.02	.04
Older	.39	.06	-.14	.04	-.10	.05	-.06	.04
Social								
Young	.43	.04	-.22	.05	-.09	.04	-.08	.04
Older	.34	.04	-.02	.05	-.04	.05	-.18	.04
Meaningful (Natural + Social)								
Young	.48	.02	-.24	.03	-.16	.03	-.03	.03
Older	.36	.03	-.08	.03	-.07	.03	-.12	.03
<i>M</i>	.42		-.16		-.12		-.07	
Abstract								
Young	.34	.04	-.14	.05	-.12	.05	-.06	.04
Older	.24	.05	.00	.06	-.08	.03	-.03	.03
<i>M</i>	.29		-.07		-.10		-.05	

Table 5Mediation Analyses for Cell Viabilities in the Meaningful Context ($N = 96$)

	Cell A			Cell B			Cell C			Cell D		
	<i>B</i>	<i>SE B</i>	β	<i>B</i>	<i>SE B</i>	β	<i>B</i>	<i>SE B</i>	β	<i>B</i>	<i>SE B</i>	β
Age	.06	.02	.28**	-.08	.02	-.37**	-.05	.02	-.22*	.05	.02	.23*
Speed	.09	.02	.39**	-.11	.02	-.44**	-.08	.02	-.34**	.04	.02	.18
WM	.06	.02	.24*	-.09	.02	-.35**	.06	.03	-.23*	.06	.02	.25**
Age with Speed	.00	.03	.00	-.03	.03	-.12	.01	.03	.05			
Speed with Age	.09	.03	.40**	-.08	.03	-.35**	-.09	.03	-.38**			
Age with WM	.05	.02	.22*	-.06	.02	-.27**	-.03	.02	-.15	.03	.02	.16
WM with Age	.04	.03	.06	-.07	.03	-.25*	-.04	.03	-.17	.04	.02	.19

**
 $p \leq .01$.*
 $p \leq .03$.

Table 6

Mean Signed Viabilities of Positive vs. Negative and Sufficiency vs. Necessity Tests by Context

Context	+Cause		-Cause		+Outcome		-Outcome	
	Stest		Ntest		Stest/Ntest		Ntest/Stest	
	A vs. B	C vs. D	A vs. B	C vs. D	A vs. C	B vs. D	A vs. C	B vs. D
	M	SE	M	SE	M	SE	M	SE
Natural								
Young	.75	.05	-.21	.04	.62	.04	-.24	.04
Older	.45	.07	-.04	.04	.38	.06	-.05	.04
Social								
Young	.59	.07	-.01	.05	.39	.04	-.11	.06
Older	.30	.05	.11	.05	.29	.05	.12	.04
Meaningful (Natural + Social)								
Young	.67	.04	-.11	.03	.51	.03	-.17	.03
Older	.37	.04	.03	.03	.33	.04	.03	.03
M	.32		-.04		.30		-.01	
Abstract								
Young	.42	.07	-.04	.05	.35	.05	-.07	.06
Older	.21	.07	-.04	.03	.25	.06	.02	.04
M	.32		-.04		.30		-.02	

Table 7

Mediation Analyses for Positive/Negative Tests and Sufficiency/Necessity Tests in the Meaningful ($N = 96$) and Abstract ($N = 48$) Contexts

	+Cause			-Cause			+Outcome			-Outcome		
	Stest			NTest			Stest/Ntest			Ntest/Stest		
	A vs. B			C vs. D			A vs. C			B vs. D		
	B	SE	β	B	SE	β	B	SE	β	B	SE	β
Age	.15	.03	.43**	-.07	.02	-.30**	.09	.03	.32**	-.10	.02	-.39**
Speed	.20	.03	.56**	-.09	.02	-.34**	.14	.03	.47**	-.11	.03	-.40**
WM	.16	.04	.40**	-.08	.03	-.30**	.09	.03	.29**	-.12	.03	-.39**
Age with Speed	.03	.04	.08	-.03	.03	-.12	-.01	.04	-.02	-.06	.03	-.22
Speed with Age	.18	.04	.50**	-.06	.04	-.25	.14	.04	.49**	-.07	.04	-.24
Age with WM	.11	.03	.33**	-.05	.02	-.21*	.07	.03	.24*	-.07	.03	-.28**
WM with Age	.11	.04	.27**	-.06	.03	-.22*	.06	.03	.20	-.09	.03	-.28**

p ≤ .01.

*
p ≤ .04.