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Do Deductive and Probabilistic Reasoning Abilities Decline in Older Adults?

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This present study investigated whether older adults' ability to accurately discriminate between deductive and probabilistic reasoning tasks declines with age, and whether this ability correlates with cognitive ability as measured by the Montreal Cognitive Assessment (MoCA) test. Seventy-eight adults (65–92 years) were tested for their abilities to carry out deductive and probabilistic reasoning. Pearson correlations were conducted to determine the relationships among age, MoCA, deductive reasoning, probabilistic reasoning, and overall discrimination ability. Separate single-factor analyses of variance were used to determine differences across age groups (65–74, 75–84, 85–94) on the MoCA, deductive and probabilistic reasoning, and overall discrimination ability. Ability to discriminate between the two tasks did not decline with age, nor did they correlate with scores of cognitive ability as measured by the MoCA. Furthermore, those with MoCA scores showing mild cognitive impairment appeared to retain all of these abilities. This leads to the conclusion that reasoning abilities may be retained while general cognitive skills decline. This in turn supports the notion that reasoning, both deductive and probabilistic, may be more domain specific than they are often considered to be.

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The ability of older adults to carry out reasoning tasks is of great practical significance given the quickly growing size of the senior citizen population (Akushevich, Kravchenko, Ukraintseva, Arbeev, & Yashin, 2013; Goldstone, 2010), and their need to make daily decisions around important issues (Appelbaum, 2007; Kim, Karlawish, & Caine, 2002). Research has shown that general cognitive decline is associated with aging (Bishop, Lu, & Yankner, 2010; Boyle et al., 2013; Salthouse, 2009) through the use of tests such as the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005) that assesses major cognitive domains including memory, visuospatial abilities, executive function, attention, concentration, and language. In contrast to global assessments, the research presented here is novel in its examination of more specific cognitive abilities involved in pure reasoning, thereby providing information about the trajectories of cognitive subskills in life's later decades. Relatively little is known about the specific mechanisms carrying out reasoning and whether these mechanisms are reliant on global or very specific cognitive systems, making the study of reasoning in the context of general decline potentially informative. Reasoning can be defined as our ability to form and evaluate conclusions based on evidence (del Mas, 2004). Categories of reasoning can be further divided into two main areas: deductive and probabilistic reasoning (Osherson et al., 1998). Examples of each one are presented in Figure 1.

Reasoning skills are necessary for developing both conclusions, as well as for judging the veracity of one's proposed conclusions. It should be noted that there are important differences between these two types of reasoning. In deduction, the conclusion is certain to be true as long as the premises are true. This is due to the valid form of the argument. In the probabilistic argument, the conclusion is only suggested by the premises. Furthermore, in deduction, all of the information necessary to reach the conclusion is included in the premises. In probabilistic

Deductive Reasoning	*Probabilistic Reasoning*
If Paul scores again, he will win the game. *Paul scores again.* *Paul will not lose the game.*	*If Paul scores again, he will win the game.* *Paul scores again.* *Paul will be happy.*

reasoning, however, it is necessary to draw upon world knowledge. The ability to accurately carry out both types of reasoning is vital for carrying out problem solving and for making appropriate decisions in all areas of life, and not just those limited to self-care and financial decisions (Boyle et al., 2012).

The MoCA (Nasreddine et al., 2005) is a tool used as a screening test for mild cognitive impairment (MCI). Out of a possible score of 30, 26 and above is considered normal. The MoCA is a valid measure of MCI (sensitivity = 90%; specificity = 87%), with good reliability ($\alpha = .83$; Nasreddine et al., 2005). The assessment was used to determine whether either or both types of reasoning were significantly lower in those showing signs of MCI. Although studies using brain imaging (Goel & Dolan, 2004; Goel, Gold, Kapur, & Houle, 1997; Osherson et al., 1998; Parsons & Osherson, 2001) and electrophysiology (Malaia, Tommerdahl, & McKee, 2015) have directly compared the neural correlates of the two reasoning types in young adults, to date, no studies have directly compared deductive and probabilistic reasoning in older adults. Furthermore, behavioral experiments on deductive abilities of an older population have yielded varied results (Arenberg, 1974; Polack, Overton, Rosenfeld, & Rosenfeld, 1995). Given that no behavioral tests have been used that measure participants' ability to distinguish between deductive and probabilistic reasoning, each brain imaging study has developed its own sample syllogisms. Osherson et al. (1998) support this type of test design by emphasizing the clear distinction between the two types of stimuli due to validity being an objective property of arguments. Although researchers using spatial brain monitoring, such as positron emission tomography, presented all of one type of reasoning in a block followed by the other type, Malaia et al. (2015), using electroencephalogram, were able to mix the two-problem types, so that participants were unaware of which type of problem would be presented next. As this is more representative of reasoning in real life, their format was used for the current research.

Although a direct comparison of the two types of reasoning abilities has not been carried out on a population of older adults, some studies have been performed on deductive reasoning abilities of older adults. Arenberg (1974) examined men ranging from their 20s to their 80s in which deductive problems around the notion of food poisoning were presented. Participants were required to make a series of deductions to determine which single food out of eight presented ones was poisonous. Out of 12 questions, results showed that men in their 20s averaged 10.3 the first time they took the test. Results declined with each decade, as the men in their 50s averaged 8.4 correct responses, which then declined to 6.9 in their 70s and 3.5 in their 80s. A study with results in opposition to Arenburg's is Polack et al. (1995), which compared two groups with mean ages of 19 and 81 on Wason-type selection problems that require logical responses about the connection between what is on the front and back of a group of cards to be selected based on rules. Although the younger group outperformed the older group on problems with strong emotional content, both groups performed equally on problems rated as not having strong emotional content. When one-half of each group was provided with a meta-cognitive strategy for solving the problems, this performance difference disappeared. The strategy consisted of instructing participants to state aloud as they assessed each card of every selection problem “Will this card help me decide if the rule is being broken?” The authors emphasized that deductive competence does not decline with age, but that performance in this area can suffer due to mitigating factors such as affect.

Information regarding probabilistic reasoning and aging comes mainly as a by-product of multifactor studies without detailed reporting of each subfactor (Castro-Costa et al., 2011; Li et al., 2004), or in using probabilistic reasoning as a component of a larger measure such as fluid intelligence (Baltes, Dittmann-Kohli, & Kliegl, 1986; Willis, Jay, Diehl, & Marsiske, 1992). Because of this, relatively less information about definitions of probabilistic reasoning and tasks used to assess it is available. In order to gain a clearer indication of reasoning abilities in older adults, the present study was designed to compare deductive and probabilistic reasoning to age as well as general cognitive ability as reflected by MoCA scores.

Methods

Participants. A total of 78 adults (51 women and 27 men) between the ages of 65 and 92 recruited from the local community, via a university-based fitness program for older adults and a residence for an active elderly population who were capable of independent living, were recruited for this study. All appropriate ethical guidelines for conducting human research were followed. This study was approved by the institutional review board at the University of Texas at Arlington based on NIH regulations relating to research involving human subjects. All participants provided informed consent.

The group was divided into the following age ranges: 65–74 years (8 men, 14 women, mean age = 70.2), 75–84 years (13 men, 23 women, mean age = 78.6), and 85–94 years (6 men, 14 women, mean age = 88.2). Exclusionary categories for participants included having known neurological difficulties, having a native language other than English, and scoring 0/5 points on the delayed-recall task section of the MoCA. This last criterion was chosen for the reason that a participant with this memory score may be unable to process a full three-line syllogism due to the task’s memory requirements.

Procedures and Materials. The reasoning assessment designed for this study consisted of three-line syllogisms similar to those given in the example in

Figure 1, except for the fact that the final sentence was put into the form of a question for evaluation. An example of each type follows:

Premises: If the baby is crying, her face will get wet.
The baby is crying.
Question 1: Is her face dry? (Correct answer: "certainly yes" due to argument validity)
Question 2: Is the baby happy? (Correct answer: "probably no" based on world knowledge)

In such a task, participants respond using a 5-point response tool, similar to that of Galotti, Komatsu, and Voelz (1997), and are asked to give one of the following responses: certainly yes, probably yes, I don't know, probably no, and certainly no. Participants are initially trained, in a session immediately preceding the actual study, in order to get used to the response tool. Participants are expected to display an ability to distinguish between certain and probable answers and to reflect their answers using the response tool. A total of 30 valid deductive arguments and 30 probabilistic arguments are included in the assessment. Stimuli consist of 15 problems meant to elicit a "certainly yes" answer, 15 designed to elicit a "certainly no" answer, 15 to elicit a "probably yes" answer, and 15 more designed to elicit a "probably no" answer. Only one specific answer was allowable for each set of stimuli. Unlike other studies, the two conditions are not separated into separate testing blocks, but are mixed in order to fully test participants' ability not only to carry out each type of reasoning, but also to decide which type of reasoning is appropriate in each case.

The MoCA was administered to each participant. Each participant who earned a score of 1–5 on the delayed-recall task section continued onto the training to use the response tool, a 5-point Likert-type scale with visual images representing the points on the scale (see Figure 2). The response tool, similar to that used by Galotti et al. (1997), consisted of a piece of wood akin to a wide ruler that had five shallow cups attached to it. Alongside this tool was a plasticized strip with a character associated with each choice, with physical expressions ranging from a very positive smile at the top to a very negative frown at the bottom. The researcher explained that the uppermost response should be chosen when answering "certainly yes" (representing logical entailment), with the others in descending order representing "probably yes," "no feeling either way," "probably no," and "certainly no" (again representing logical entailment). These images served as an aide-memoire to remember which hole represented which answer. Participants were instructed to answer each question by placing a ball into one of the five holes. A practice session, with questions such as "Is your name?" and "Will it rain this Sunday?," was provided in order to verify that each participant could appropriately distinguish between certain and probability

Figure 2. Response tool used to collect participant responses.

information and represent it using the response tool. Participants were also allowed to ask for the sentences or the instructions to be repeated at any time without penalty.

Given that no established test of deductive and probabilistic reasoning exists, stimuli sets were designed by the researcher, which is the same practice carried out in every neurological analysis comparing the two types of reasoning to date (Goel et al., 1997; Goel & Dolan, 2004; Malaia et al., 2015; Osherson et al., 1998; Parsons & Osherson, 2001). However, this study went beyond the others in using more than intuition to judge the probability level of the non-deductive question, basing their categorizations on the opinions of an expert panel made up of a linguist, a logician, a psychologist, and a teacher. The researcher read aloud a syllogism with the last line being presented as a question. Participants were instructed to treat the premises as true. The participant responded to each question with one of the five responses. Thirty questions represented valid deductions requiring the use of modus ponens, a simple rule of inference that could be paraphrased as "A implies B; A is stated as being true; therefore B is true." For these 30 questions, half were designed to solicit an answer of "certainly yes" and the other half of "certainly no" (see Figure 1, "Deductive Reasoning"). Thirty questions were non-valid in the logical sense, meaning that the premises did not entail the conclusion, but what were estimated to be a highly probable or highly improbable conclusions as agreed upon by the panel (see Figure 1, "Probabilistic Reasoning"). The probabilistic task was also evenly divided between questions meant to elicit the responses "probably yes" and "probably no." Each participant was given a score out of 30 for deduction, and a score out of 30 for probabilistic reasoning. In order to be awarded with a point, the participant's response had to be correct both regarding deductive versus probabilistic, as well as in valence. Deductive and probabilistic arguments were not separated by blocks, but instead mixed similarly to the arguments used by Malaia et al. (2015) to ensure that participants were deciding what type of reasoning was appropriate for each question asked. Language difficulty and length of argument in both conditions was controlled for, as all question types used the same set of premises. Potential conclusions were also controlled for number of words (deductive mean = 5.0, probabilistic mean = 5.5), and number of clauses (deductive mean = 1.00, probabilistic mean = 1.27).

Statistical Analyses. Three scores were calculated: one for correctly answered deductive questions, one for "correctly" answered probabilistic questions, and a sum of the two scores. The maximum score of each category was 30, meaning that the maximum combined score was 60. Note that probabilistic responses are not able to strictly be called "correct" due to their dependency on personal experience. This limitation has also been noted in all of the past neurological studies comparing the two reasoning types. For example, in Figure 1, an argument is presented as being invalid but highly probable when stating that, if Paul scores again and wins the game, that he will be happy. Parsons and Osherson (2001) make clear that no objective standards of accuracy can exist for probability tasks as they are dependent on personal experience. In order to be awarded with a point on the invalid arguments, the participants needed to agree with the predicted response of a panel of experts, and were not answered as if they were logically valid, following the example of Malaia et al. (2015). The advantage in awarding points only when a specific response was chosen gave greater assurance that the participants had understood the syllogisms and the task.

Statistical analyses were performed using SAS 9.4. Pearson's correlations were used to determine the relationship among age, MoCA, deductive reasoning, probabilistic reasoning, and overall discrimination ability. Separate single-factor ANOVAs were used to determine differences among age groups (65–74, 75–84, 85–94) on the MoCA, deductive reasoning and probabilistic reasoning, and overall discrimination ability. Tukey–Kramer post hoc tests were used to compare significant effects. Values are presented as means and standard deviations, and $p < .05$ was considered significant.

Results

Pearson correlations among variables are presented in Table 1. A significant negative correlation was found between age and the MoCA, $r = -.289$. The MoCA was also significantly positively related to probabilistic reasoning, $r = .283$. Overall discrimination was, of course, significantly related to probabilistic ($r = .565$) and deductive ($r = .739$) reasoning. All other comparisons were non-significant.

The ANOVA results comparing the effects of age on the MoCA, probabilistic reasoning, deductive reasoning, and overall discrimination ability are presented in Table 2. As shown in Table 2, there was a significant age effect for MoCA scores, $p = .035$. MoCA scores for the 85- to 94-year-old subjects ($M = 24.9$, standard deviation [SD] = 3.7) were significantly lower than MoCA scores for 65- to 74-year-old subjects ($M = 27.0$, $SD = 2.9$), $d = .64$, but not 75- to 84-year-old subjects ($M = 26.7$, $SD = 2.1$), $d = .59$. The 65- to 74-year-old subjects were not significantly different from the 75- to 84-year-old subjects. MoCA scores significantly decreased with age, with 23% of the 65- to 74-year-old subjects scoring below normal (MoCA <26), 33% of the 75- to 84-year-old subjects scoring below normal, and 35% of the 85- to 94-year-old subjects scoring below normal, $p < .001$. There were no significant differences in probabilistic reasoning ($p = .351$), deductive reasoning ($p = .689$), or overall discrimination ability ($p = .964$) between the three age groups.

Table 1

Correlations Among Age, Reasoning, and Montreal Cognitive Assessment (MoCA)

	Age	MoCA	Probabilistic	Deductive
MoCA	−.289			
Probabilistic	.024*	.283*		
Deductive	−.015	.006	−.139	
Overall discrimination	−.029	.198	.565**	.739**

*$p < .05$. **$p < .001$.

Table 2

Effects of Age on Reasoning and Montreal Cognitive Assessment (MoCA)

	Age groups (mean ± *SD*)				
	65–74	75–84	85–94	*diff-crit*[b]	*p*
n	22	36	20		
MoCA	27.0 ± 2.9	26.7 ± 2.1	24.9 ± 3.7[a]	1.919	.035
Probabilistic	9.0 ± 6.9	7.0 ± 5.2	8.2 ± 4.5	3.822	.351
Deductive	19.4 ± 7.9	20.8 ± 6.5	19.7 ± 6.2	4.719	.689
Overall discrimination	28.4 ± 9.4	27.8 ± 7.7	27.9 ± 8.0	5.684	.964

[a]85- to 94-year-old significantly different from: 65- to 74- and 75- to 84-year-old, $p = .035$.
[b]*q-crit* = 3.38155.
SD = standard deviation.

Discussion

The major findings of this present study was that neither deductive nor probabilistic reasoning skills showed significant signs of decline with aging, nor did either ability decline in the population showing MCI. These results indicate that certain specific abilities, such as deductive and probabilistic reasoning and the ability to distinguish between logical and probabilistic arguments, may be more resistant than other skills in the face of declining cognition. These results coincide with, and extend, the results of Yang, Liang, Lu, Li, and Zhong (2009) who found that patients with MCI had behavioral performances on probabilistic reasoning comparable with those undergoing normal aging. These studies provide identification of cognitive skills that appear to be resistant to both normal aging processes and MCI, at least to the degree that MCI is measured by the MoCA.

The findings of the current study seem to indicate that skills involved in reasoning are less affected by aging than those skills of the major cognitive domains that are measured by the MoCA. This in turn supports the notion that reasoning is more domain specific than the more generalized aspects of cognition such as executive function, visuospatial abilities, memory, etc. Furthermore, as the results showed a significant correlation to exist between MoCA scores and probabilistic reasoning, but not between MoCA scores and deduction, it is possible to put forward the hypothesis that between the two reasoning skills, deduction is more localized and more specific than probabilistic reasoning. This notion is supported by findings from past research exploring the differences between these two reasoning types including Malaia et al.'s (2015) results showing that deduction was a faster and more likely automatized process than was probabilistic reasoning. Goel and Dolan's results (2004) complement this idea, suggesting that deduction relied heavily on part of the linguistic processing system focused on syntax. This is an appealing suggestion in that syntax is strongly related to logical form and it is possible that the deductive network could be described as one focusing on rule application. Although Parsons and Osherson (2001) rejected the idea that deduction relied on linguistic processing, they make the suggestion that deduction relies on neural substrates that comprise a logic-specific network. Probabilistic reasoning has, on the other hand, generally been seen by the same authors as more general than deduction, probably relying on more diverse neural correlates. Current results also support this hypothesis, although not to the point that probabilistic reasoning actually declined with age.

It should also be noted that not only were deductive and probabilistic reasoning skills found to remain intact with increasing age, but nearly as importantly, the ability to distinguish between the two and to choose and apply the correct ensuing processing remained intact. This is encouraging news, given the widespread use of reasoning in daily life. With further research, this finding may be of use in the development of training programs for older adults to compensate for other areas of cognitive degeneration. Consider, for example, a patient suffering from a mild memory impairment who needs to take medication each day. They may find themselves unable to remember whether or not they took their medication 1 day due to the flawed memory system; however, they may be able to be trained to use deductive reasoning to determine whether or not they have taken their medicine by, for instance, placing the container in one of two spots, on alternating days, after they have taken their medication. If the container has not been moved to the appropriate spot (e.g., the left side of the counter) for the current day (e.g., Wednesday), they can logically deduce that they have not taken their medication. Note that this is only one example, and there are likely many ways to take advantage of the intact reasoning systems to improve the quality of life of older adults. Attention must be called to the fact that the participants in this study were relatively well educated and active, which may limit the application of findings to other groups. Further longitudinal testing and an examination of older adults with different characteristics including more severe cognitive impairment are needed to provide additional insight into the nature of these cognitive processes and their resistance to cognitive decline. Indeed, older adults are the fastest growing segment of the population; by 2030, they will make up 20% of the total population (about 72 million citizens; He, Sengupta, Velkoff, & DeBarros, 2005). Therefore, more research is greatly needed to keep up with this trend in order to develop effective cognitive training programs for these older adults.

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