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Conservation of *species*, *volume*, and *belief* in patients with Alzheimer's disease: the issue of domain-specificity and conceptual impairment

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Abstract

Two studies investigated whether patients with Alzheimer's disease (AD) suffer high-level and category-specific impairment in the conceptual domain of living things. In Study 1, AD patients and healthy young and healthy elderly controls took part in three tasks: the Conservation of Species, Volume, and Belief. All 3 tasks required tracking an object's identity in the face of irrelevant but salient transformations. Healthy young and elderly controls performed at or near ceiling on all tasks. AD patients were at or near ceiling on the Volume and Belief tasks, but only about half succeeded on the Species task. Study 2 demonstrated that the results were not due to simple task demands. AD patients' failure to conserve species indicates that they are impaired in their theoretical understanding of living things, and their success on the Volume and Belief tasks suggests that the impairment is domain-specific. Two hypotheses are put forward to explain the phenomenon: the first, a category-specific account, holds that the intuitive theory of biology undergoes pervasive degradation; the second, a hybrid domain-general/domain-specific account, holds that impairment to domain-general processes such as executive function interacts with *core cognition*, the primitive elements that are the foundation of domain-specific knowledge.

Keywords

Alzheimer's disease; aging; cognitive development; intuitive biology; domain specificity; conceptual impairment; Piagetian conservation

Conservation of species, volume, and belief: Studies of possible category-specific conceptual impairment in patients with Alzheimer's disease

Recent findings in cognitive neuropsychology suggest that concepts of *living things*—animals in particular—may be especially vulnerable to certain kinds of brain damage (Capitani, Laiacina, Mahon, & Caramazza, 2003; Caramazza & Shelton, 1998; Forde & Humphreys, 1999; Tyler & Moss, 2001; Zannino, Perri, Pasqualetti, Di Paola, Caltagirone, & Carlesimo, 2006). Caramazza and his colleagues have suggested that impairments in reasoning about animals is due to a genuinely *category-specific deficit* in the domain of living things. They have suggested that, for evolutionary reasons, knowledge about animals (as *predators* and *prey*), as well as fruits and vegetables (as *food* and *toxins*), have special status in the conceptual

system, special locations in the brain, and consequently special vulnerabilities to certain kinds of brain damage (Caramazza & Shelton, 1998).

Domain-general accounts of the impairment have also been proposed. According to the *Sensory-Functional* theory, living things are primarily distinguished by their *sensory* properties. In contrast, nonliving things (such as artifacts), are primarily distinguished by their *functional* properties (Allport, 1985; Gainotti & Silveri, 1996; Hart & Gordon, 1992; Shallice, 1988; Silveri & Gainotti, 1988; Warrington & Shallice, 1984; Warrington & McCarthy, 1983, 1987). Any damage specific to sensory features would therefore preferentially affect concepts of living things. In short, what seems like a deficit to a specific *category* may really be a deficit to a specific type of *feature*. According to another domain-general or non-categorical account, the *Organized Unitary Content Hypothesis* (Caramazza, Hillis, Rapp, & Romani, 1990; Hillis, Rapp, & Caramazza, 1995; Rapp, Hillis, & Caramazza, 1993), categories whose members have highly correlated properties occupy particularly *dense* regions in semantic space. Focal damage to a dense region will lead to disproportionate impairment to the category occupying that space. Since the category of living things has a high degree of feature correlation among category members, it is particularly dense – and particularly vulnerable.

As Caramazza and Shelton (1998) have argued, however, neither of these accounts is very compelling. With respect to the *Sensory-Functional* theory, studies have shown that patients with a specific deficit in reasoning about living things are just as impaired in reasoning about animals' *functional* features as their *sensory* features – a finding clearly at odds with the theory (Funnell & De Mornay Davies, 1997; Laiacona, Barbarotto, & Capitani, 1993; Laiacona et al., 1997; Sheridan & Humphreys, 1993). The *Organized Unitary Content Hypothesis* fares better with respect to the evidence, but this may be, as Caramazza and Shelton (1998) suggest, because it is an inadequately constrained theory to begin with, able to explain virtually any finding. (For a fuller discussion of both of these accounts, see Caramazza & Shelton, 1998.)

Though these particular domain-general accounts are flawed, it is still a matter of active debate whether the impairment ought rightly to be considered domain-general or domain-specific. The goal of the present study is twofold: first, we wish to enlarge the boundary of investigation by expanding the very notion of a conceptual domain and seeing whether such an expanded notion leads to a fuller and richer description of the conceptual problem. Second, we wish to see whether this fuller and richer description might tell us something important about the locus of the difficulty, favoring either a domain-specific or domain-general account. We begin with a brief summary of the literature on category-specific deficits in intuitive biology in patients with Alzheimer's disease.

Alzheimer's disease

Several studies of patients with Alzheimer's disease have reported the presence of a category-specific impairment for living things (Whatmough & Chertkow, 2002) in at least a substantial minority of AD patients. Tasks on which patients have shown category effects include identification questions (Chertkow & Bub, 1990), picture naming (Daum, Riesch, Sartori, & Birbaumer, 1996; Garrard, Patterson, Watson, & Hodges, 1998; Laiacona, Barbarotto, & Capitani, 1998; Silveri, Daniele, Giustolisi, & Gainotti, 1991; Zannino, Perri, Carlesimo, Pasqualetti, & Caltagirone, 2002; Perri, Carlesimo, Zannino, Mauri, Muolo, Pettenati, & Caltagirone, 2003), word-to-picture matching (Silveri, et al., 1991; Zannino, et al., 2002; Perri et al., 2003), semantic probe questions (Daum, et al., 1996; Perri et al., 2003), drawing (Mauri, Daum, Sartori, Riesch, & Birbaumer, 1994), and similarity ratings (Chan, Butters, & Salmon, 1997). As noted, not all AD patients exhibit category-specific impairment and several studies failed to find a significant group effect (Cronin-Golomb, Keane, Kokodis, Corkin, & Growdon, 1992; Gonnerman, Andersen, Devlin, Kempler, & Seidenberg, 1997; Hodges, Salmon, &

Butters, 1992; Montanes, Goldblum, & Boller, 1996; Tippet, Grossman, & Farah, 1996). Nevertheless, it now appears that at least some AD patients perform significantly worse on living objects than on nonliving objects (Whatmough & Chertkow, 2002).

The taxonomy of living things

One way to understand the conceptual category *living things*, indeed, the dominant characterization in the neuropsychological literature, is as a hierarchically organized taxonomy, with more general concepts (*animal, plant*) at the top, more specific concepts (*dog, lettuce*) in the middle, and still more specific concepts (*poodle, Romaine*) at the bottom (Berlin, Breedlove, & Raven, 1973; Brown, 1958; Martin, 1992; Medin & Atran, 2004; Rosch, Mervis, Grey, Johnson, & Boyes-Braem, 1976). Neuropsychologists have designed tasks to explore the representation of features at various levels in the taxonomy and several studies have found greater loss of features at the bottom level of the taxonomy (Hodges, Salmon, & Butters, 1992; Martin & Fedio, 1983; Moss, Tyler, & Jennings, 1997; Zannino, et al., 2002). For example, while patients might have trouble identifying a zebra as a zebra rather than as a horse, they will not have trouble identifying it as an animal rather than as a vegetable. From these data, it has been argued that AD patients' conceptual deficit in the category *living things* is a relatively low-level, bottom-up impairment. Although this claim accords with the results of explorations of the taxonomy, we feel it may be premature.

A different notion of a 'conceptual domain'

Cognitive scientists, philosophers, and developmental psychologists -- all concerned with issues of 'domain-specific' knowledge -- provide us with a somewhat different notion of *conceptual category* or *domain* than the primarily taxonomic one described in the neuropsychological literature. Not only does a conceptual domain specify a taxonomy, it also has, at its core, a rich and powerful set of causal concepts that do much of the work in explaining the phenomena captured in the domain. As laid out in seminal work by Carey (1985), the conceptual domain of living things includes such concepts as *life cycle, bodily machine, respiration, birth, disease, and death*. These concepts include functions, mechanisms, and processes -- all of which play a causal role in biological events. Furthermore, many of these processes are defined in terms of one another (e.g., *conception* and *birth* are early stages in the *life cycle*; *disease* is a malfunction in the *bodily machine*; *death* is the cessation of *respiration* and other bodily processes). This relationship between concepts speaks to the *coherence* of the domain. Coherence reflects the fact that knowledge of a domain entails more than a list of isolated facts or even a large taxonomy; it also entails richly specified mechanisms and powerful general principles that support inference and explanation. Indeed, this domain is often referred to as an *intuitive theory*, an *intuitive biology*.

As we see it, the tasks most commonly used by neuropsychologists -- category fluency, picture naming, word-to-picture matching, questionnaires involving superordinates, subordinates, perceptual features, and the like -- are extremely well-suited to exploration of the taxonomy of living things and they have led to rich contributions in our understanding. However, they were not designed to test the integrity of the domain at its *theory* level (Lombrozo, Kelemen, & Zaitchik, 2007; Zaitchik, Koff, Winner, Brownell, & Albert, 2004; Zaitchik & Solomon, 2001). It will take a different type of task to explore the integrity of the core concepts that form the heart of our intuitive biology. Fortunately, a battery of tasks designed to investigate theoretical concepts already exists: Developmental psychologists have been particularly interested in the domain of living things, in part because of the special perceptual and attentional mechanisms dedicated to tracking features such as faces, eyes, gait, and autonomous motion that are specific to animals (e.g., Bertenthal, Proffitt, Spetner, & Thomas, 1985; Gelman, 1990; Johnson, Dziurawiec, Ellis, & Morton, 1991; Johnson & Carey, 1998; Leslie, 1994; Massey & Gelman, 1988; Spelke, Phillips, & Woodward, 1995). A rich theoretical and

empirical literature describes the growth and elaboration of conceptual knowledge in our intuitive theory of living things, our intuitive biology.

In Zaitchik and Solomon (2008), we borrowed a task from developmental psychology that was specifically designed to test a core concept in intuitive biology: the concept *alive*. We found that, like young children, most AD patients and some healthy elderly adults attributed life to inanimate objects that are active or in motion (e.g., the sun, fire). In contrast to the *taxonomic* impairments described in the neuropsychological literature, this finding describes impairment at the level of intuitive *theory*.

Species kind – a core intuitive biological concept

In the present studies, we look again to developmental psychology for well-established methods with which to investigate conceptual understanding in the domain of living things, in both healthy elderly and in patients with AD. We ask two questions: First, do age or AD lead to further conceptual change in intuitive biological reasoning? That is, is there further conceptual impairment at this higher, theoretical level? Second, if so, is the difficulty domain-specific or would well-matched tasks in other conceptual domains reveal similar impairments?

To answer our first question, we focus on AD patients' understanding of the concept of *species*. *Species*, like *living thing*, is a central concept in intuitive biology. Its acquisition in childhood is taken to indicate the development of a more coherent understanding of a whole range of phenomena concerning living things (Carey, 1985; Gelman, 2003; Keil, 1989; Medin & Atran, 2004; Solomon & Johnson, 2000). Keil's (1989) Species Transformation task taps the extent to which children's understanding of species is like that of healthy young adults, judging that an animal's species is causally determined by the species of its birth parents, rather than by its surface properties. In Keil's study, children were told stories in which animals of particular species undergo various kinds of superficial transformations of differing permanence. These transformations ranged from putting a costume on a chicken so that it looks like a turkey, to painting black stripes on a horse so that it looks like a zebra, to giving pills to a baby tiger that cause it to lose its stripes and grow a mane like a lion. Keil found that very young children judged even the most temporary transformations, such as costume change or painting, to change species kind. Early elementary school-aged children still judged animals capable of species change, though they required the acquired changes to be increasingly more drastic than did the younger children. By age 10, however, children deny that an animal can change its species. Like adults, they reason that an animal's species is determined by its parentage and that species kind is already fixed by the time of the animal's birth.

Developmental researchers have further demonstrated that, certainly by the time they are adolescents, children have constructed an intuitive biology like that of adults, believing that though surface properties may be *characteristic* of an animal kind (e.g., stripes are characteristic of raccoons), they are not *essential*. A raccoon would still be a raccoon even if the stripes were altered; an altered raccoon would never become, for example, a skunk. Adolescents and adults reason as if there were something *essential* about an animal's species kind, something that is deep and immutable (Keil, 1989; Medin & Atran, 2004; Wellman & Gelman, 1998).

Research on intuitive biology has focused on the *acquisition* of such knowledge. This is due to the widespread assumption that, once acquired, intuitive biology remains relatively stable throughout the lifespan. Researchers have therefore tended to focus on children and young adults or on members of non-Western societies whose intuitive biology may be qualitatively different from that of young adults in the West. While developmental psychologists still disagree about the precise timetable of particular conceptual acquisitions in early childhood, there is consensus that, at least by late adolescence, children in a variety of social contexts

construct an intuitive biology with this kind of essentialist understanding of animal kind (Astuti, Solomon, & Carey, 2004; Bloch, Solomon, & Carey, 2001; Jeyifous, 1992; Medin & Atran, 2004). What we do not know is what happens to it once it has been acquired.

There has been little interest among developmental psychologists in investigating changes in intuitive biology in older people. However, given the increasing evidence of changes in thinking with age (Albert, 2001; Backman, Small, & Wahlin, 2001) and of taxonomic changes in animal concepts with AD (Perri, et al., 2003; Silvieri, et al., 1991; Zannino et al., 2002; Zannino, et al., 2006), and given our earlier discovery of animism in both healthy elderly and AD patients (Zaitchik & Solomon, 2008), it is surely an important empirical question. In the present study, we test whether healthy elderly and patients with AD maintain the commitment to essentialism and the ability to conserve species kind across superficial transformations.

Domain-specificity

If the species transformation task does uncover evidence of impairment that goes beyond the taxonomy – that is, impairment at the *theory* level of intuitive biology – we are led to ask our second question: Is the difficulty limited to the domain of living things? Is intuitive biology especially vulnerable to the effects of aging or disease, or is the difficulty more domain-general? To address this question, we presented two tasks that are similar to the species task in important ways, tasks that tap some of the same general abilities, but that do not involve concepts from the domain of intuitive biology. We chose the Conservation of Volume task that draws on conceptual understanding from the domain of intuitive physics, and the False Belief Task that draws from the domain of intuitive psychology.

Conservation tasks (Piaget, 1955; Piaget & Inhelder, 1941) were designed to test whether children could perform the cognitive operations necessary to track particular properties (e.g., volume, mass, or number) across superficial transformations. In the volume task, participants are presented with two identical containers filled with equal amounts of water. The contents of one container are poured into a wider container in which the water level does not reach as high. By age 7, most children correctly judge that the amount of water has not changed, despite the appearance of change.

In the False Belief task (Gopnik & Astington, 1988; Perner, Leekam, & Wimmer, 1987; Zaitchik, 1990; 1991), participants are shown a familiar container, such as a Band-Aids box, then asked what is inside. The box is then opened to reveal surprise contents, such as a tissue. The box is then closed up as it was originally. Participants are asked what they *thought* was in the box before it was opened, and what someone else entering the room and seeing the box *all closed up like they first saw it* would think was in it. By age 4, children succeed on both questions, a success that marks a major benchmark in children's developing understanding in the conceptual domain of intuitive psychology.

These two tasks share several important properties with the Species Task outlined above. Most importantly, in each case, participants must track identity across superficial transformations. For that reason, all three tasks could be characterized as conservation tasks (Flavell, Miller, & Miller, 1993): the Conservation of Species, Volume, and Belief (from here on, referred to as the Species, Volume, and Belief tasks, respectively). In the Species task, participants must ignore a salient but irrelevant transformation in the animal's perceptual features and maintain focus on the animal's unchanged species kind. Similarly, in the Volume task, participants must ignore the salient but irrelevant transformation of the water level in the glass and maintain focus on the unchanged amount of water. In the Belief task, participants must ignore the salient but irrelevant transformation of their own belief about the contents of the box and maintain the perspective of their past belief.. In all three tasks, the transformation constitutes a powerful source of interference, interference that must be ignored.

In using tasks that tap conservation abilities in three distinct conceptual domains, we test for domain-specific conceptual impairment in healthy elderly and AD patients. That said, we understand that neither the Volume nor the Belief task is a perfect control for the Species task, but as an initial exploration of comparability across domains, we believe that they do roughly control for several important domain-general processes involved in the Species task. Like the Species task, they require an ability to detect, hold in memory, and reason about conflicting representations. Most importantly, they demand the ability to ignore very salient perceptual information that might serve as a quick and easy identification heuristic and instead to respond using theoretical knowledge. To a first approximation, any general difficulty in attention or working memory that leads to impairment on the Species task should lead to similar problems on the Volume and Belief tasks.

Study One: Conservation of Species, Volume, and False Belief

Method

Participants—Twenty *Healthy Young* adults (7 men, 13 women; mean age 20 years, range 18–23) and twenty *Healthy Elderly* adults (10 men, 10 women; mean age 74 years, range 65–82) were recruited from the general public in the Greater Boston area. Twenty-three *patients with Alzheimer's disease* (7 men, 16 women; mean age 80 years, range 73–93) were recruited from the Gerontology Research Unit of the Massachusetts General Hospital in Boston and the Hebrew Rehabilitation Center for the Aged. The mean MMSE score of the AD patients was 22.5, with a range of 9–30. Participants took part in all three tasks, with the Conservation of Species task coming first, followed, in order, by the Conservation of Volume and Conservation of False Belief tasks.

Conservation of Species task—The procedure for the Species task is based on Keil's (1989) species transformation study. Participants were told two stories of animals whose appearances were altered by various means such that they came to look like animals of another species: a tiger who was made to resemble a lion and a raccoon who was made to resemble a skunk. As each story was told, participants were shown a line drawing, one of the animal before the operation and one after. These drawings were presented side by side on a single piece of paper and were visible throughout the task.

Here is a picture of a big tiger. Some doctors came and performed a special operation on him. Here's what they did: First, they used special fur bleach to take away his stripes. Then they sewed on a huge lion's mane so he ended up looking like this. After the operation, what is he, a tiger or a lion? How do you know that he is a [tiger/lion]?

Now I want to show you a picture of a raccoon. Some doctors came and performed a special operation on her. Here's what they did: first, they shaved away some of her fur; then dyed the rest of it black. After that, they bleached a single stripe, all white, down the center of her back. Then, with surgery, they put into her body a sac of super smelly odor just like a skunk has. When they were done, she looked like this. After the operation, what is she, a skunk or a raccoon? How do you know that she is a [raccoon/skunk]?

Notice that the first story involves changes in external features only while the second story involves an internal change as well. Both stories involve salient transformations to the animals described, but none of these transformations determines species kind, according to normative intuitive biology.

Conservation of Volume—The procedure for the Volume task (based on Piaget, 1955, and Piaget & Inhelder, 1941) was designed to test whether children could track characteristics such as volume or mass in the face of superficial transformations. In the first trial, participants are

presented with two identical containers filled with equal amounts of water. After establishing that the participant believes they contain the same amount of water, the experimenter pours the contents of one container into a very different empty container. This new container is much wider, so that the water level doesn't reach as high. The experimenter then asks the Test Question "Does one cup have more water in it, or do they both have the same amount of water?"). In a second trial, the experimenter presents the two identical containers, establishes that the participant sees them as equally filled, then drops a large wooden block into one of them, thereby raising the water level markedly. Again, the participant is asked the Test Question.

Conservation of Belief—The procedure for the Belief task is based on Gopnik and Astington (1988). In the first trial, participants were shown a familiar container (i.e., a Band-Aids box), then asked what was inside. After participants answered that it had the expected contents inside (i.e., Band-Aids), the experimenter opened the box to reveal surprise contents (e.g., a tissue), and asked, "What's really in the box?" The box was closed again. The participant was then asked the *Self* Test Question ("What did you think was in the box before I opened it up?") and the *Other* Test Question ("If I asked someone else to come into the room now and they saw the box all closed up like it is now, what would they think is in it?"). In a second trial, a paperclip box filled with a rubber band was used.

Results

Conservation of Species—As can be seen in Table 1, Healthy Young and Healthy Elderly participants performed nearly perfectly on the Species task. All but 2 of the 20 Healthy Young participants answered both questions correctly (they were correct 95 percent of the time on the tiger/lion story and 90 percent of the time on the raccoon/skunk story). Similarly, all but one of the 20 Healthy Elderly answered both questions correctly (they were correct 100 percent of the time on the tiger/lion story and 95 percent of the time on the raccoon/skunk story).

AD patients, by contrast, performed poorly on the task as a group. Only 8 of the 23 AD patients answered both questions correctly. On the tiger/lion story, despite the fact that all of the described transformations were external and superficial, only 65 percent of AD patients correctly conserved species. On the raccoon/skunk story, which involves a salient internal as well as external change, only 35 percent of AD patients conserved species. More importantly, a chi-square analysis indicates that the 35 percent of AD patients who correctly judged that species type would be conserved on both transformation stories is significantly less than the 95 percent of Healthy Elderly controls, $\chi^2_{(1)} = 16.603, p < .001$.

Conservation of Volume—All participants—healthy young, healthy elderly, and AD patients—responded correctly to both trials of the *Volume* task (see Table 1). Not a single participant was deceived by the salient but irrelevant transformations of water level. Our result is important for it demonstrates that even the most impaired AD patients in our study were able to track identity across superficial transformations, albeit in the domain of intuitive physics.

Conservation of Belief—As Table 1 indicates, participants were also successful on the Belief task. All Healthy Young controls answered all questions perfectly, as did nearly all of the Healthy Elderly and AD patients. Collapsing across questions and trials, Healthy Elderly answered a mean of 99 percent of questions correctly, and AD patients answered a mean of 98 percent of questions correctly. There were no significant differences among the performances of the Healthy Young, Healthy Elderly, and AD patients. This result again demonstrates the spared ability of AD patients to ignore an irrelevant but salient transformation, this time in the domain of intuitive psychology.

Overall—Across the three tasks, the most striking finding is how poorly the AD patients performed on the Species task relative to the performances of the other participants and to their own performances on the other tasks (see Table 1). We note that there was no significant correlation of age with performance, either within the group of AD patients or pooling the healthy elderly and AD patients. Age difference does not appear to be a confound for these results. In order to capture the reasoning patterns of individual participants across the tasks, we characterized three patterns of judgment: 1) those who answered all questions correctly on all three tasks; 2) those who answered all questions correctly on the Volume and Belief tasks, but made at least one error on the Species task (a pattern consistent with there being a category-specific impairment in reasoning about living things); and 3) those who showed some other pattern.

As can be seen in Table 2, nearly all of the Healthy Young and the Healthy Elderly answered all of the questions correctly on all three tasks. By contrast, only about one-third of AD patients answered all of the questions correctly. Importantly, 14 of the 15 remaining AD patients answered all of the Volume and Belief questions correctly but made at least one error on the Species task. The probability (binomial theorem) of an individual participant's showing such a pattern by chance is .012. A second-order application of the binomial theorem indicates that the 14 AD patients who showed such selectively impaired performance is significantly more than would be expected by chance out of a group of 23, $p < .001$. Moreover, the 14 AD patients answered an average of only 23 percent of the species transformation questions correctly.

The individual performances of the AD patients were further analyzed to determine whether they could be considered to have displayed a classical dissociation, that is, whether their performance was impaired in one domain, but normal on the other (Crawford, Garthwaite, & Gray, 2003). The data for each individual AD patient on the Species task and the Belief task were compared to those of the Healthy Elderly controls using the RSdT (Crawford & Garthwaite, 2005), a means of testing for deficits and dissociations in single-case studies. The results show that 14 of the 23 AD patients showed a significant discrepancy in their performances in the two domains ($p < .001$) and can be classified as classically dissociated, with significant impairment on the Species task ($p < .001$), but not on the Belief task (Crawford & Howell, 1998).

Justifications of species judgments—The justifications participants provided for their own species judgments beautifully illustrate differences in underlying intuitive biology. For correct species judgments, justifications overwhelmingly manifest an *essentialist* view of animal kind (i.e., the belief that there is something deep and defining about species membership) and the *biological* knowledge that species kind is determined by parentage. Species kind, then, is *immutable*, no matter the superficial alterations. The following are telling examples of justifications of the correct judgment that a raccoon who looks and smells like a skunk is still a raccoon: “because [it] can’t change species”; “because pre-op it was a raccoon”; “because of [its] genetic make-up”; “because it only superficially changed appearance and odor”; “because fundamentally [a raccoon] is what she is, despite appearance”; “because only her appearance has changed”; “because smell is not the defining attribute of a skunk”; “because they just changed her appearance but she is really still a raccoon”; “because ... if she has a baby it will be a raccoon, not a skunk”; “because you can’t change species”; “because she started out as a raccoon”; “because an animal can’t be changed by an operation”; “because you can’t make her something she isn’t”. For these participants, then, having a skunk-like appearance, even having a surgically implanted smelly sac, does not turn a raccoon into a skunk. Presumably, the characteristic features of a skunk are only indicative of species kind when they are acquired *in the right way* – by biological inheritance from skunk parents.

In contrast, *every* incorrect species judgment, whether from young controls, from healthy elderly, or from AD patients, was justified by appeal to the animal's appearance ("because of her fur"), odor ("because she smells"), or both. These are precisely the characteristic justifications of young children who fail to conserve species on this task (Keil, 1989).

Study 2: Belief Story task

Results of the classic tasks presented in Study 1 rule out the broad claim that AD patients have a domain-general loss of conservation skills – that is, that they cannot recognize and ignore an irrelevant transformation. Similarly, the results appear to rule out the broad claim that AD patients have trouble detecting conflicting representations and resolving them correctly. Instead, they suggest that patients' conceptual problems may be *particularly manifested in* the domain of intuitive biology. Nevertheless, as noted above, the Volume and Belief tasks of Study 1 are not perfectly matched for the Species task. We attempted to control for the most obvious confounds, but of course it is possible to consider others. In this follow up study, we engage a reasonable alternative explanation of Study 1 that invokes task demands: it might be argued that poor performance on the Species task was due to a loss of interest or attention to the story or a loss of memory for relevant story facts. Recall that the stimuli used in the control tasks (cups of liquid, boxes, paperclips, etc.) are real three-dimensional objects, while the stimuli used in the Species task are illustrated narratives. To test this hypothesis, Study 2 presented the same participants with a Belief task more closely conforming to the design of the Species task. Like the Species task, the Belief Story task of Study 2 presented participants with stories accompanied by illustrations. (Indeed, to provide a more stringent test of our hypothesis of a *specific* deficit in intuitive biology, we designed our Belief stories to be even longer and more complicated than our Species stories.) Like the Species stories, the Belief stories required the manipulation of two representations (species: tiger and lion; belief: ignorance and knowledge).

Method

Participants—The twenty Healthy Young, twenty Healthy Elderly, and twenty-two patients with Alzheimer's disease who took part in this study had also participated in Study 1. One patient with Alzheimer's disease from Study 1 was unavailable for this study. The mean MMSE score of the AD patients was 22.6, with a range of 10–30.

Belief Story task—The procedure for the Belief Story task is based on Mant & Perner (1988) and was originally designed to test whether children could track other people's beliefs and expectations. In the stories below, the character's belief starts out true and only becomes false because of changes in the world of which the character is unaware.. Participants heard four stories of the following sort:

Frank and Roy are reading in the library. Frank says to Roy "tonight I'm going to the movie theater. Why don't you meet me there at 8:30?" Roy says "Sure. See you there." [Participants are shown illustration 1.] After a while, Roy goes home for supper. Then he gets dressed and starts walking to the movie theater. He expects to find Frank there. [Participants are shown illustration 2.] Meanwhile, Frank doesn't feel like going to the movie theater anymore. He decides to stay in the library and read some more. [Participants are shown illustration 3.] [Participants are then asked Question 1: Does Frank go to the movie theater?]

Roy is still on his way to the movie theater. [Participants are shown illustration 4.] [Participants are then asked Question 2: Does Roy know that Frank is not going to the movie theater? Yes, he knows that Frank is not going; or no, he doesn't know?]

The study tests whether participants can understand and remember the facts of the story, as tapped by Question 1, and whether they can maintain their understanding of what a character believes to be true (e.g., does Roy believe that Frank will go to the movie theater?) despite the change in external reality (e.g., that Frank has decided not to go to the movie theater), as tapped by Question 2. Notice that these stories, are longer and more detailed, than those of the Species task, involving two different people whose movements and beliefs must be remembered. This control task would appear to make greater memory and verbal comprehension task demands than does the Species task. To the extent that the poor performance of the AD patients on the Species task in Study 1, relative to their performance on the Volume and Belief tasks, was due to task demands rather than to some aspect of conceptual reasoning in intuitive biology, then the AD patients in Study 2 should also show relatively poorer performance on the Belief story whose task demands are at least as strong as those of the Species task.

Results

As can be seen in Table 3, the Healthy Young and Healthy Elderly answered all questions perfectly. The AD patients were similarly successful: They answered the Factual Question correctly an average of 97 percent of the time across trials, and they answered the Belief question correctly an average of 94 percent of the time across trials. This finding undermines the strong claim that poor performance on the Study 1 Species task was due to domain-general task demands associated with the comprehension of illustrated stories and memory for story facts.

While the difference in performance across domains certainly suggests a specific impairment in intuitive biology, it may never be possible to fully control for every conceivable domain-general task demand. Fortunately, there is another source of evidence that the difficulty of AD patients on the Species task is conceptual (i.e., intuitive biological) rather than due to an uninteresting general task demand. This source of evidence lies within the Study 1 Species task itself. Recall that performance on Story 1 (Lion/Tiger) was almost twice as good as performance on Story 2 (Raccoon/Skunk). These stories were nearly identical save for one property: the transformations to the animal in Story 1 were all external (fur bleached, mane sewn on), while those in Story 2 included an internal change as well. This change, a surgically inserted body organ highly characteristic of a skunk (a smelly sac) made a significant difference in patients' judgments of species membership. Of course, the concept *body organ* is firmly planted in *intuitive biology*. With a mature and intact intuitive biology, as seen in almost all the Healthy Young and Elderly participants, the manner of acquisition of body organs *matters* to the species identity: while it is true that smelly sacs are highly associated with skunks, it is only if the smelly sac is acquired through a *biological* process (in this case, *birth*) that the animal is a skunk. The fact that it no longer matters to AD patients how an animal's properties are acquired is good evidence that they are not reasoning about species kind as they did just several years earlier, before they began to suffer from AD. To reiterate our point, the difference in performance between the two trials of the task, trials with identical demands on processing but different demands on theoretical reasoning within the domain of intuitive biology, provides further evidence that the poor performance on the Species task is not fully explainable as the effect of domain-general task demands.

General Discussion

The present studies were designed to answer two questions: First, do age or AD lead to impairment in *theoretical* reasoning in the conceptual domain of living things? And second, is this domain particularly vulnerable to such impairment relative to other domains? In answer to the first question, we argue that AD patients' poor performance on the Species task speaks to an impaired ability to reason about a concept at the very core of our intuitive biology. On a

task on which almost all children succeed by age 10, and on which healthy elderly perform as well as healthy young people, roughly half of the AD patients judged that an animal's species would change as a result of alterations in perceptually salient but biologically irrelevant features.

In answer to our second question, the performances of the majority of AD patients showed a classical dissociation. The near perfect performance of these AD patients on control tasks in the conceptual domains of intuitive physics and intuitive psychology (Study 1) suggests that the observed impairment in intuitive biology is not due to a domain-general decline in reasoning ability alone. On these control tasks, which also require the ability to conserve underlying realities in the face of salient but theoretically irrelevant transformations, patients show no evidence of difficulty. Indeed, of the 15 AD patients who made errors on *any* of the conservation tasks, 93 percent performed perfectly on the Volume and Belief tasks and made errors *only* on the Species task. This pattern of results suggests that intuitive biology may be *particularly* vulnerable to impairment. The success of AD patients on the Belief Story task of Study 2 supports this claim as well. Though the Study 2 belief stories were even longer and more complicated than the Species stories of Study 1, involving more story characters and more events, AD patients had no trouble at all. This supports our earlier claim that failure on the Species task is not due to processing demands involved in comprehension of illustrated stories. As noted above, we understand that our control tasks cannot rule out every conceivable domain-general explanation. Nevertheless, we think they provide compelling evidence that the most plausible domain-general explanations – those that appealed to deficits in working memory, attention, narrative comprehension, the appearance-reality distinction, the ability to ignore irrelevant transformations – were not likely to explain the failure to judge species. At least in part, there would appear to be something special about intuitive biology. But what? We offer two hypotheses as to why reasoning in intuitive biology should be so vulnerable: the first a domain-specific account and the second, a hybrid domain-general/domain-specific account.

A domain-specific explanation

First, let us consider a domain-specific explanation of the phenomenon. The failure of AD patients to conserve species is of a piece with our earlier finding that the majority of AD patients attribute life to such inanimate objects as the sun, the rain, and fire (Zaitchik & Solomon, 2008). *Species* and *living thing* lie at the very heart of our intuitive biology. One might speculate as to why these central concepts of intuitive biology should be vulnerable. At a descriptive level, of course, the performances of the AD patients in this task resemble those of young children. With children, failure to judge that an animal's species kind will remain unchanged despite superficial transformations in appearance is taken as evidence that they have not yet constructed an understanding of *biological inheritance*, of the causal role that reproduction and parentage play in determining species kind (Johnson & Solomon, 1997; Solomon, Johnson, Zaitchik, & Carey, 1996). With adults, however, the cause of failure on the task could be different. After all, adults are unlike children in that they know many more facts relevant to making a successful judgment (Astuti, Solomon, & Carey, 2004; Springer, 1996). Even adults with AD know more of the relevant facts than do children.

Rather, on this domain-specific account, we argue that for the AD patients who failed the species task, intuitive biological reasoning itself is impaired. It may be that particular concepts (e.g., *species*) have become degraded or that the overall conceptual structure has lost its coherence or stability. Whatever the exact source of the problem, it is safe to say that the understanding of birth and reproduction no longer plays the inferential role it played, providing the necessary causal knowledge to conserve species across superficial transformations. We further suggest that when intuitive biological reasoning is impaired, we tend to fall back on particular default patterns of reasoning (Lombrozo et al., 2007). Attention to surface

appearance and the weighting of typical properties in judgments of kind identity may be just such a reasoning bias. It would therefore be salient for young children who have not yet constructed a biological understanding of inheritance, and for patients with AD, whose biological understanding is no longer salient or accessible. Put another way, the outcome of the conflict between appearance and reality that was set up by all three conservation tasks may depend on the strength and stability of the underlying intuitive theory. As noted above, it is the role of theories – both formal theories and intuitive theories – to take us further from the surfaces of things and deeper into their underlying realities. Intuitive biology allows us to categorize animal kinds according to *biological* criteria rather than surface appearances. As this theory becomes weaker or less accessible, the tendency to quickly categorize animals according to their perceptual properties – a generally useful heuristic strategy for object recognition – may become more attractive. Of course, this non-theoretical strategy, which conflicts with our intuitive biology, leads to failure on the Species task. So long as the conceptual degradation is domain-specific, so should the concomitant impaired inference be domain-specific. Though the results of this study support a claim of domain-specific impairment in intuitive biology, the claim must still be considered preliminary until it can be tested using other control tasks. Given the difficulty of finding perfect control tasks, we will follow up on this initial study with a more comprehensive approach, one which delves more widely and deeply into each of a number of conceptual domains, investigating a large range of concepts and causal principles to see whether a similar type or degree of conceptual impairment is to be found across domains. A finding of widespread and pervasive loss in intuitive biology, but spared intuitive theories of psychology or physics, would provide convergent evidence in favor of the hypothesis suggested by our present findings.

An alternative account: domain-general processes meet core cognition

We speculate that a hybrid domain-general/domain-specific account might also explain our findings. On this view, impairment to domain-general processes such as executive function interacts with *core knowledge*, the primitive elements that are the foundation of domain-specific knowledge (Carey & Spelke, 1996; Carey, 2009). Reasoning in the conceptual domain of intuitive biology is *particularly* vulnerable because, as a domain, it makes especially great demands on executive control processes. This demand stems from the fact that intuitive biology develops out of a conceptual structure – a behavioral theory of animals – with which it is incompatible (Carey, 1985). Our innate perceptual and attentional mechanisms are dedicated to identification of animals' *behavior* – not their *biology*. Insofar as they remain so dedicated, our attention to behavior and surface appearance may demand constant suppression in order for us to reason biologically.

We are currently investigating this hypothesis by examining the relationship between individual subjects' performance on intuitive biology tasks and executive function tests. If this hypothesis is correct, then impairment in executive functions – those processes necessary for holding conflict in mind, for detecting it, and for resolving it will more greatly disturb intuitive biology than other conceptual domains. This hypothesis would make sense of the fact that young children, whose executive function skills are not yet mature, and AD patients, whose executive function skills are diminished (Amieva, Phillips, Della Sala, & Henry, 2004; Belleville, Chertkow, & Gauthier, 2007) make identical errors on the species conservation task, just as they did on the animism task. It would also make sense of the fact that intuitive biology is a relatively late acquisition in childhood, and a relatively early loss in dementia.

This hypothesis is a bit of a hybrid. It rests on a clearly domain-specific phenomenon – the evolutionary endowment that makes identification of *agents*, of prey and predator, a central player in the phenomena we describe. As Caramazza and his colleagues have noted, we are designed to respond preferentially to living things. This response is not based on sensory vs

functional features, it is not based on general patterns of feature correlation or distinctiveness. It is based on the fact that we are designed to privilege living things. Of course, every domain-specific conceptual structure comes in contact with domain-general processors. If humans are hardwired to attend to properties of living things that conflict with our intuitive biological theory, then it will be the job of these general processors to detect and resolve the conflict. This hypothesis, then, appeals to the interaction of domain-specific knowledge and domain-general processors. If this view is right, we should expect a similar impairment in reasoning to manifest itself in any domain in which canonical adult reasoning requires the suppression or inhibition of hardwired, or early-arising perceptual and attentional predispositions. As noted above, we are currently designing studies to investigate this speculation.

Beyond our particular characterization of conceptual impairment in intuitive biology in patients with AD and our speculations as to its underlying nature, and apart from its eventual confirmation or disconfirmation, we believe that these studies confirm the benefit of the interdisciplinary integration of the literatures and methodologies in developmental psychology and cognitive neuropsychology. Studies of concept acquisition, conceptual change, and conceptual impairment are likely to be mutually informative and mutually constraining, and such integration promises to yield further rich results.

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Table 1

Mean percentage of questions answered correctly in each conservation task, by group.

	Volume	False belief	Species
Healthy young (n=20)	100	100	93
Healthy elderly (n=20)	100	99	98
AD patients (n=23)	100	98	50

Table 2

Number of participants showing each pattern of responses across the tasks, by group.

	All tasks correct	Volume & Belief tasks correct; errors on Species task	Other
Healthy young (n=20)	18	2	0
Healthy elderly (n=20)	18	1	1
AD patients (n=24)	8	15	1

Table 3

Mean percentage of questions answered correctly on Study 2 questions, by group.

	Factual	First-order false belief
Healthy young (n=20)	100	100
Healthy elderly (n=20)	100	100
AD patients (n=22)	97	94