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Some consequences of normal aging for generating conceptual explanations: A case study of vitalist biology

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ABSTRACT

Accumulating evidence suggests that not only diseases of old age, but also normal aging, affect elderly adults' ability to draw on the framework theories that structure our abstract causal-explanatory knowledge, knowledge that we use to make sense of the world. One such framework theory, the cross-culturally universal vitalist biology, gives meaning to the abstract concepts *life* and *death*. Previous work shows that many elderly adults are animists, claiming that active, moving entities such as the sun and the wind are alive (Zaitchik & Solomon, 2008). Such responses are characteristic of young children, who, lacking an intuitive theory of biology, distinguish animals from non-animals on the basis of a theory of causal and intentional agency. What explains such childlike responses? Do the elderly undergo semantic degradation of their intuitive biological theory? Or do they merely have difficulty deploying their theory of biology in the face of interference from the developmentally prior agency theory? Here we develop an analytic strategy to answer this question. Using a battery of vitalist biology tasks, this study demonstrates—for the first time—that animism in the elderly is due to difficulty in deployment of the vitalist theory, not its degradation. We additionally establish some powerful downstream consequences of theory deployment difficulties, demonstrating that the elderly's use of the agency theory is not restricted to animist judgments—rather, it pervades their explicit reasoning about animates and inanimates. Extending the investigation, we identify specific cognitive mechanisms implicated in adult animism, finding that differences between young and elderly adults are mediated and moderated by differences in inhibition and shifting mechanisms. The analytic strategy developed here could help adjudicate between degradation and deployment in other conceptual domains and other populations.

1. Introduction

Diseases of old age, as well as normal healthy aging, lead to cognitive impairments, impairments both in domain general cognitive capacities (e.g., memory, executive function) and in the representation of or deployment of specific conceptual content. With respect to the latter, studies of patients with a variety of brain-diseases [stroke, Herpes Simplex Encephalitis, and Alzheimer's disease (AD)] have reported conceptual impairment specific to the domain of *living things*. That is, such patients perform worse on questions about animates (e.g., *Does a zebra have stripes?*) than similar questions about inanimates

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(e.g., *Does a teapot have a lid?*; see Whatmough & Chertkow, 2002, for review). In one study (Hodges, Salmon, & Butters, 1992), a group of Alzheimer's patients was presented with tests of category fluency, picture naming, spoken word-picture matching, picture sorting, and generation of verbal definitions. Analysis of errors for each patient showed that it was the *same* animals that led to errors across the tasks—that is, the same animals whose names were not generated, whose pictures were not correctly named, matched or sorted, and whose properties were not generated in a verbal definition (Hodges et al., 1992). This pattern of item-specific failures, across tasks that vary not only in processing demands but also in the type of knowledge that must be retrieved (name, shape, surface feature, etc.), has been taken to support the claim that errors reflect *degradation* of specific concepts rather than general problems with information retrieval or semantic processing (i.e., problems with the *deployment* of intact semantic knowledge). Surprisingly, the finding of relatively worse performance naming animates than inanimates was recently extended to healthy elderly adults (Coppens & Frisinger, 2005), raising the possibility that even normal aging may involve impairment of conceptual knowledge in this domain.

On the basis of such findings, it has been claimed in the clinical neuropsychology literature that the conceptual domain of living things, the focus of the present study, is especially vulnerable to degradation (for review, see Capitani, Laiacona, Mahon, & Caramazza, 2003). Specifically, it has been argued, in the hierarchically organized taxonomy of living things—a hierarchy with animals at the top, dogs further down, collies or golden retrievers still further down, and so on—there is loss of low level features of specific animal concepts (for example, as noted above, whether zebras have stripes).

However, the domain of living things is more than a taxonomy; it is conceptualized in terms of framework *theories*, rich and coherent structures with their own sets of inter-defined concepts, structured in terms of theory-specific causal-explanatory principles. One cross-culturally universal theory of living things, known as *vitalist biology*, is one of a few framework theories that structure our understanding of the biological world. It is constructed by children over a protracted period, from ages 5 to 12 (Carey, 1985; Inagaki & Hatano, 2002). Vitalist biology gives meaning to the foundational abstract concepts *life* and *death*. Degradation, or problems deploying, *these* concepts would reverberate through reasoning and inference. The semantic memory literature alluded to above finds that impairment is *limited* to low levels of the semantic hierarchy—loss of details that distinguish one wild cat from another, one bird from another. However, contrary to this generalization, there is mounting evidence for impairment of the central theoretical concepts that structure causal-explanatory reasoning. Such impairment may often be found among patients with diseases of aging, but it is found as well in normal healthy elderly.

1.1. Impairments (due to degradation or deployment) across several framework theories

The first report, long ago, was that many elderly adults, presented with Piagetian conservation tests, respond like young children, failing to conserve weight, volume, and area (as reviewed in Hooper, Fitzgerald, & Papalia, 1971). These concepts articulate a framework theory of matter that is constructed in early adolescence (Carey, 2009; Piaget & Inhelder, 1974). In this early study, the elderly were not screened for diseases that affect cognition. More recently, Moran, Jolly, and Mitchell (2012) found that elderly (screened with the Mini-Mental State Exam only) show impairments in theory of mind tasks, failing to attribute false beliefs, and fail to take intentions into account when evaluating morality. Similarly, Zaitchik and Solomon (2009) found that adults in the early stages of AD responded like young children on the Species Transformation task (Keil, 1989). Here participants are presented with a story about a raccoon that has undergone plastic surgery so that it comes to resemble a skunk. Asked what kind of animal it is after the surgery, patients with mild AD responded that it is a skunk. This response is typical of preschool children who have not yet constructed the framework theory within intuitive biology organized around concepts of reproduction and the distinction between properties inherited from biological parents and properties acquired by acculturation. In another study, Lombrozo, Kelemen, and Zaitchik (2007) found that adults in the earlier stages of AD, again like children, accepted unwarranted teleological explanations for the *existence* and *properties* of kinds (e.g., *Why is there rain? So that plants and animals have water for drinking and growing. Why is the sun so bright? So that animals and plants have enough light to survive.*). Which teleological explanations are warranted and which are not depends upon causal-explanatory knowledge, the very causal explanatory knowledge that structures framework theories. Finally, and most relevant to the present study, Zaitchik and Solomon (2008) reported a similar effect when healthy elderly, as well as patients with mild AD, were presented with a Piagetian Animism test. More than half of the AD patients responded like young children, asserting, for example, that the sun is alive. Surprisingly, almost a third of the healthy elderly—a group of participants who had undergone rigorous medical screening for inclusion in the study as *healthy* elderly controls—responded the same way, attributing life to inanimate objects. Childhood animism is one of the signature reflections of the absence of the framework theory of vitalist biology.

These regressive phenomena are counterintuitive and puzzling. The knowledge underlying the canonical adult responses in these tasks is developed in childhood, reliably used in adulthood, and surely deeply entrenched over the course of a lifetime. Why might some elderly adults, especially *healthy* elderly adults, revert to the response patterns of 4- to 6-year-olds? The same two overarching interpretations as those that articulate the semantic memory literature have been offered for the reemergence of childhood responses among the elderly.

1.1.1. The degradation account

On the one hand, it is possible that later-developing abstract conceptual knowledge may be degraded by diseases of old age, or even in the course of normal aging (the degradation account). For example, Lombrozo et al. (2007, p. 14, emphasis added) interpreted promiscuous teleology as an 'explanatory default', a life-long preference that becomes evident "when

causal beliefs that might otherwise constrain it are limited or compromised." Similarly, Zaitchik and Solomon (2008, p. 35, emphasis added) interpreted the existence of animist responses in the healthy elderly and AD patients to be "a consequence of the well-maintained salience of activity and motion in the face of a *degraded folkbiology*."

1.1.2. The deployment account

Another possibility is that the relevant abstract conceptual knowledge is preserved, but the ability to deploy that knowledge is diminished. With respect to the healthy elderly, for example, it is possible that normal age-related weakening of information-processing mechanisms might lead to difficulty in deploying the more mature and later acquired theories or causal beliefs—even when these theories and causal beliefs are intact. Indeed, even young adults show difficulties deploying high-level causal knowledge when information-processing demands are excessive. Several studies have shown that putting healthy young adults (or even professional scientists) under cognitive load, or under instruction for speeded response, reveals interference from the earlier developing systems of knowledge. For example, Kelemen and Rosset (2009) found that educated young adults making speeded judgments show the heightened acceptance of teleological explanations that constitutes promiscuous teleology. Shtulman and colleagues showed that responses based on developmentally earlier theories interfere with generating correct responses consistent with later developing theories, causing errors or slower processing, across a wide range of intuitive and schooled theories. Over ten different theory pairs, accuracy is higher and RTs to judge statements true (or false) are faster, if the statement is true (or false) according to both the earlier and later developing theories, than if the statement is true on one of the theories and false on the other (Shtulman & Valcarel, 2012). Notably, this interference effect is greater in older adults (Shtulman & Harrington, 2016).

Most relevant to the present study, Goldberg and Thompson-Schill (2009) presented college students and biology professors with a judgment task similar to the Animism Interview. Participants were asked to categorize moving and nonmoving inanimate entities, animals, and plants into the categories *alive* or *not alive*. Critically, the task was presented under speeded conditions (maximum time to respond was 1 s). In this speeded presentation, both college students and biology professors were less accurate when classifying plants as alive than when classifying animals. Though professors were a bit more accurate than students, they still showed longer response times to plants than to animals. Furthermore, when classifying inanimate entities as not alive, students and professors were less accurate with *moving* and causally potent inanimates (e.g., fire) than *nonmoving* inanimates (e.g., simple artifacts or rocks). Moreover, correct responses were slower to moving than nonmoving inanimates. Most revealing of all, those inanimate entities that proved difficult for these adults—moving and active objects (*airplane, taxi, star, cloud,* etc.)—were precisely the same kinds that were difficult for preschoolers and for healthy elderly in a non-speeded presentation (Carey, 1985; Laurendeau & Pinard, 1962; Zaitchik & Solomon, 2008).

1.2. When problems of deployment might be expected

All the regressive phenomena mentioned above—failures of conservation, animism, species transformation, false belief attribution, moral reasoning, and promiscuous teleology—share two important features. First, they all involve competition between a correct response and an incorrect but prepotent response that is triggered in the context of the particular task or question posed to the study participant. In the case of non-conservation and the species transformation studies, the prepotent response depends upon perceptual features: one quantity looks like more, in spite of the two quantities being the same; or the transformed animal looks like a different kind in spite of that transformation being superficial (the result of paint, costumes, or plastic surgery). In the case of promiscuous teleology, functional explanation is a default explanatory bias, making the teleological explanation a prepotent response. In the case of the false belief task, the prepotent response is the true state of affairs, and in moral evaluations the prepotent response is based on caused harm. With respect to errors of childhood animism, the prepotent response derives from the developmentally earliest framework theory in which *animal* is a theoretical term—the agency theory. This theory, that construes animals as causal and intentional agents, is evident even in infancy (see Carey, 2009, for review).

Second, in all cases, the developmental processes that underlie the child's capacity to resist the prepotent lure involve construction or elaboration of the framework theories that structure cognition. That is, the childhood transition away from the immature and earlier developing prepotent response involves the construction of new causal-explanatory knowledge. Piaget himself saw the transition to conservation of amount of matter, weight, volume, as reflecting theory construction within a theory of matter (Piaget & Inhelder, 1974), and his interpretation has been confirmed in subsequent work (Smith, 2007; Smith, Carey, & Wiser, 1985; see Carey, 2009, for review). With respect to promiscuous teleology, Kelemen and colleagues attribute its developmental decline to school-based acquisition of detailed knowledge of mechanistic causal processes, knowledge that then constrains explanations for the existence and properties of kinds of objects. They speculate, we think convincingly, that the promiscuous teleology they documented in young Roma (gypsy) adults is due, at least in part, to the absence of such explicitly taught causal-explanatory knowledge (Casler & Kelemen, 2008); indeed, they additionally suggest that the degradation of such knowledge explains the reemergence of promiscuous teleology in AD (Lombrozo et al., 2007). With respect to species transformation judgments, the adult pattern of responses is supported by later developing causal knowledge of the process of reproduction and the processes through which kind-dependent properties of animal kinds are fixed (Keil, 1989; Solomon & Johnson, 2000; Springer & Keil, 1989). With respect to the false belief task, the prepotent reality error disappears at around age 4, with the acquisition of the explicit representational theory of mind (Perner, 1991; Wellman, 2014; Wellman & Liu, 2004). Similarly, between ages 4 and 8 or so, immature moral evaluations disappear

as children demonstrate an elaborated moral theory in which human intentions play a central role (Cushman, Sheketoff, Wharton, & Carey, 2013; Piaget, 1965/1932). Finally, childhood animism declines as a function of the construction of a vitalist biology (Bascandziev, Zaitchik, & Carey, 2015; Carey, 1985; Carey, Zaitchik, & Bascandziev, 2015; Contento, 1981; Inagaki & Hatano, 2002; Slaughter, Jaakkola, & Carey, 1999; Zaitchik, Iqbal, & Carey, 2013).

Given the interference from earlier and superseded theories that apparently remain in the conceptual system, generating immature but prepotent responses, how is it that mature theories ever get deployed? The answer must lie in the suppression of the immature responses. A suite of cognitive mechanisms known as executive functions (EFs) are involved in the selection of responses that are desirable and the inhibition of those that are not. More specifically, the EFs include working memory (actively maintaining and manipulating information), inhibition (of competing responses), and set shifting (switching between tasks or mental sets) (Diamond, 2013; Miyake et al., 2000). The finding that EFs are diminished in the elderly is well established (Babcock & Salthouse, 1990; Borella, Carretti, & De Beni, 2008; Verhaeghen, Marcoen, & Goossens, 1993). For example, older adults have demonstrated lower working memory spans on digit span tests, both forward and backward (Foos, 1989; Grégoire & Van der Linden, 1997). They have more difficulty updating information in working memory and shifting attention (Fisk & Sharp, 2004; Verhaeghen & Basak, 2005). They also show deficits in inhibitory control (Bedard et al., 2002; Gazzaley & D'Esposito, 2007; Hasher & Zacks, 1988; McDowd & Craik, 1988; Plude & Hoyer, 1986).

In sum, it is plausible that adjudicating between competing responses—and then inhibiting those that are incorrect but prepotent—makes demands on executive functions. If so, the age-related decline in EFs may cause problems for older adults in deploying conceptual knowledge while reasoning about and explaining real-world phenomena. The present study begins to explore this hypothesis in the domain of vitalist biology, focusing on normal aging alone. We choose this domain for two reasons: first, because the reemergence of animism shows the largest effect of all the regressive phenomena described above; and second, because the construction of vitalist biology is one of the best described episodes of framework theory acquisition in the cognitive development literature.

1.3. Vitalist biology

Adult understanding of biology is not a simple collection of facts acquired over the course of life (Carey, 1985; Carey et al., 2015; Johnson & Carey, 1998). Adult biological understanding consists of a constellation of theories (a vitalist theory of bodily function in the service of making possible activity, growth, and life itself; a theory of the reproductive origins of new animals and plants and the biological inheritance of properties; a theory of evolution, and many more). Each theory is a coherent set of inter-defined concepts and causal-explanatory principles. Whereas even infants construe animals as dispositional causal agents (Gelman & Baillargeon, 1983), and young preschoolers know many biological generalizations (e.g., animals and plants grow; you need to eat to grow, etc.) (Wellman & Gelman, 1992), each of the adult theories in the above constellation is constructed over a period of several years. Construction of the vitalist theory begins in the 5th year of life and is not fully complete, in normally developing children, until age 10 or 12 (Carey, 1985; Inagaki & Hatano, 2002). It is never achieved by some populations, such as adults with Williams Syndrome (Johnson & Carey, 1998). Vitalist biology, which appears to be a cross-cultural universal acquisition at least by adulthood (see Inagaki & Hatano, 2002), is the first childhood theory of animals in which "life" and "death" are theoretical terms. According to vitalist biology, the external world contains sources of vital energy—air, food, and water—that must enter the body and move through it, bringing energy to all its parts (Carey, 1985; Contento, 1981; Hatano & Inagaki, 1994; Inagaki & Hatano, 1993; Inagaki & Hatano, 2002). While body parts may each be specialized for a particular process, they all work together as a system whose function is to maintain life, health, and growth. Within vitalism, death is understood as the end of life, occurring because of the breakdown of those bodily functions necessary to *utilize* the vital substances derived from air and food in the service of life; it is often described as the leaving of the "life force" from the body.

1.4. The coherency of the Animism, Death, and Body Parts Interviews

While vitalism is children's first biological theory of life and death, it is not their first theory of animals. Children's initial theory seeks to explain the behaviors of animals and people. It is a theory about *agents*, beings that are active and intentional, rather than a theory about living things. As Piaget (1929) demonstrated in his classic studies of childhood animism, when young children are asked to judge whether something is alive, they always attribute life to animals, but they almost always attribute life to at least some inanimate objects as well, particularly those that appear to be capable of activity or movement. Such children often attribute life to the sun (because it moves and warms us), the wind (because it moves and blows the leaves), and fire (because it jumps around and burns things). Lamps are alive when they are on, emitting light, but not alive when they are off. In line with this reasoning, young children often deny life to plants (because they don't move and don't do anything).

Moreover, the absence of a biological understanding of *alive* makes it difficult for children to differentiate the contrast between alive and dead from the contrast between animate and inanimate (Carey, 1985). Indeed, some young children fail to differentiate *alive* from *real, visible, present*, or even just *existing* (Carey, 1985). As one might predict, young children's confusion with *alive* is reflected in parallel confusion about *death.* When asked what it means to die, they often respond that it means to stop doing things or to become invisible or simply to go away. Some children understand death as the end of existence—but not the end of life (Barrett & Behne, 2005; Carey, 1985).

Finally, and not surprisingly, young children know little about the workings of the body. When asked about the function of the body organs, preschoolers tend to report a single independent function for each body part (e.g., the heart is for beating), showing no understanding of the body as a biological system whose parts work together to sustain life (Slaughter et al., 1999). Importantly, performance on tasks that tap these basic biological concepts (*alive, dead,* and the function of body parts) are significantly correlated in individual children, consistent with the hypothesis that they diagnose a coherent underlying theory (Carey et al., 2015; Slaughter & Lyons, 2003; Slaughter et al., 1999; Zaitchik et al., 2013). Finally, training interventions that teach children how bodily processes support growth and activity naturally improve performance on interviews that tap this aspect of vitalism. More impressive, however, is that such training shows far transfer in improvements on children answers on the Animism and Death Interviews—even though "life" and "death" are never mentioned in the training sessions. Again, this is consistent with the hypothesis that these three interviews diagnose a coherent underlying theory undergoing construction in early childhood (Bascandziev et al., 2015; Slaughter & Lyons, 2003).

1.5. A research strategy: Conceptual degradation or problems of deployment?

The first goal of the present study is to develop and validate a research strategy for distinguishing between the degradation and deployment accounts of elderly adults' impairment in drawing on deep causal-explanatory understanding. Such a research strategy must, in principle, be able to provide evidence for degradation as well as deployment, and should be extendable to other conceptual domains, as well as to other populations (e.g., patients with semantic dementia or diseases of old age.)

The fact that theories are coherent, that concepts within a theory are inter-defined such that markedly different tasks will tap the same knowledge structure, provides us with the wedge we need to distinguish semantic degradation from problems in deployment. If a coherent theory undergoes degradation, the markedly different tests should show coherent declines with aging or disease. As reviewed above, the three vitalism interviews (i.e., the Animism Interview, the Death Interview, and the Body Parts Interview) tap the same coherent vitalist theory. Thus, we might expect that any semantic *degradation*, regardless of the underlying causes, would be evident across the whole range of tasks, reflecting a general instability or deterioration of the theoretical structure. In contrast, if reasoning errors are due solely to *deployment* difficulties, one should expect successful reasoning on tasks for which there are no salient prepotent lures, relative to those for which there are. The three vitalism interviews differ in this way: the Animism Interview elicits non-vitalist responses due to the agency framework for understanding the nature of animals; the Death Interview elicits spiritual construals of death as well as ones supported by vitalist biology (Harris, 2011). Failures on the Body Parts Interview, in contrast, overwhelmingly reflect mere ignorance; there is no alternative framework theory for the workings of the inner organs of the body.

The second goal of the present study is to explore the mechanisms underlying age-related deployment and/or degradation of conceptual knowledge. To do so, we must identify candidate causal factors, explore whether individual differences in these capacities predict differences among the elderly on the conceptual knowledge tasks, and see whether they mediate the group differences observed between the young and the elderly. Here we begin to explore the statistical implications of age-related declines in executive functions on the likelihood of animist responses in healthy elderly adults.

2. Methods

2.1. Participants

Thirty elderly adults (15 female) aged 66–90 (M_{age} = 77.1) were recruited through the Massachusetts General Hospital Gerontology Research Unit (Psychiatry) database and tested in a quiet room in their homes. The cognitive status of each participant was carefully reviewed to determine that there was no history of progressive cognitive decline. None of the elderly adults had conditions known to cause cognitive deficits (e.g., vitamin deficiency, electrolyte imbalance) or a history of severe head trauma, alcoholism, or psychiatric illness. Thirty-one young adults (24 female) aged 18–25 (M_{age} = 19.9) were recruited primarily from the Harvard and MIT undergraduate community and tested either in their homes or in a testing room at the Harvard Laboratory for Developmental Studies. All participants were administered the Mini-Mental State Exam (MMSE) immediately before testing (Folstein, Folstein, & McHugh, 1975) and all scored in the normal range (Elderly: M = 29.2, range = 27–30; Young: M = 29.5, range = 28–30). Participants were not compensated for participating.

2.2. Materials and procedure

2.2.1. Biology battery

Three interviews were administered to investigate the understanding of each of the three main components of vitalist biology: life, death, and bodily function.

2.2.1.1. The Animism Interview. The Animism Interview assesses the understanding of what it means to be alive by tapping into the animate/inanimate distinction, the distinction between things that live and then die (e.g., animals, plants) as opposed to things that were never alive (e.g., tables, chairs) (Carey, 1985; Piaget, 1929). First are three open-ended

questions: *What does it mean to be alive, to be a living thing? Can you name some things that are alive, that are living things? Can you name some things that are not alive, that are not living things?* Participants are then asked to make a judgment, for each of a series of entities in three object categories (animal, plant, inanimate entity), *Is X alive, is X a living thing?* In addition, we requested a justification of these yes-no judgments for one animal, one plant, and two inanimate entities, different ones for different participants. While these questions were designed to tap vitalist biology, they can activate the agency theory as well. This is because the most salient property of prototypical living things (i.e., people and animals) *is* their agency—their causal and intentional agency, their goal-directedness, which in turn play a role in explaining their self-generated motion, activity, and behavior.

2.2.1.2. The Death Interview. The Death Interview assesses the understanding of what it means to die and the knowledge that death is the *end* of life, resulting from the breakdown of bodily function (Carey, 1985; Slaughter & Lyons, 2003; Slaughter et al., 1999). The interview probes the following aspects of the concept of death: that death is *inevitable, irreversible,* involves the *cessation* of all bodily and mental function, and is *applicable* only to living things. This interview, which taps the alive/dead distinction, is likely to activate religious responses as well as the vitalist theory of biology. Participants are asked the following open-ended questions: *What does it mean to die? Can you name some things that die? What happens to a person when they die? What happens to a person's body when they die?* The following yes/no questions further probe the understanding that death is the cessation of bodily and mental function: *When a person dies, does he need to eat/pee/sleep? When a person dies, does he feel bad that he died/miss his friends/think about things?* Participants are then asked: *What might cause a person to die? Does every person die? Is there anything anyone can do to make a dead person live again? Can a doctor make a dead person live again?*

Young children, who have not yet constructed a vitalist theory, construe death as the *opposite* of life, not the *end* of life. That is, young children have not differentiated *dead* from *inanimate,* so intrusions from the agency theory of animals are observed on the Death Interview. For example, a preschooler might say that rocks are dead because they do not move by themselves (Carey, 1985). In contrast, for older children and adults, the Death Interview requires adjudicating between biological and spiritual construals of death (Harris, 2011) and is not likely to elicit intrusions related to the agentive construal of animals.

2.2.1.3. The Body Parts Interview. The Body Parts Interview (Carey, 1985; Slaughter & Lyons, 2003; Slaughter et al., 1999) probes the awareness of the functions of body parts and how they work together to sustain life. The interview first asks about the location and function of various body parts—hands, heart, brain, eyes, lungs, stomach, and blood. Then, for each of these body parts, the participant is asked what would happen if a person did not have that body part. This is followed by asking why we need food and air, how they are processed through the body, and whether a brain is required for breathing and eating.[1]. These questions tap vitalist biology alone; that is, there does not appear to be any alternative theory that could compete with vitalism as a basis for responding to questions about the function of body organs.

2.2.2. Scoring of the biology interviews

The interviews were transcribed and coded blind to participant (see Appendix A for complete interviews and scoring criteria). Across all three interviews, higher scores represent greater biological responding. Given that the Animism Interview is particularly sensitive to interference from the agency theory, qualitative explanations and justifications on this interview were coded along two dimensions: (1) biological responses that appeal to the lifecycle, to body functions and processes, and responses that attribute life to biological entities only; and (2) agency responses, those related to activity, movement, goals, social interaction, and mental states, and judgments that attribute life to at least one inanimate object. Biological explanations and justifications each received positive points, while those appealing to agency received negative points. Some questions (e.g., *What does it mean to be alive?*) could elicit both biology and agency responses and were scored for both (e.g., a subject could receive 2 points for "to breathe" and −2 points for "to move," for a total score of 0). Because both the agency theory and vitalist biology classify animals as alive, the classificatory judgments of whether each entity was or was not alive were scored only with respect to whether they reflected intrusions from the agency theory. That is, negative points were awarded for attributing life to inanimate objects, or for failing to attribute life to plants. Thus, a set of answers lacking biological reasoning and relying completely on the agency theory would yield a high negative score; a set of answers relying on biological reasoning would yield a high positive score; and a set of answers relying on both biological reasoning and agency reasoning would fall somewhere in between. Possible scores range from −12 to 10.

For the Death Interview, points were awarded for responding that death is the *end* of life (as opposed to the *opposite* of life), that it entails the cessation of all mental and biological functions, and that the body decomposes after death. Points were also given for recognizing that death is inevitable and irreversible for all living things. Given that the Death Interview might reasonably elicit religious responses, points were subtracted for religious/spiritual responses only if they were not

[1] The first eleven elderly participants were administered a slightly different version of the Body Parts Interview. The earlier version probed the function and importance to sustaining life of the same seven body parts used in the later version, though with a slightly different order and wording. It then asked about the need for and importance of food, water, and air. There were no differences between versions in any aspect of the results. Overall scores, as well as variance in scores, were comparable (Earlier version: 0.80 (0.05); Later version: 0.82 (0.12)).

qualified as such, or if they were given in response to a question that clearly required a biological explanation (e.g., explaining what happens to a person's *body* after death). Possible scores range from −11 to 10.

For the Body Parts Interview, points were awarded for mapping bodily functions onto body organs, for knowing that bodily organs are critical for sustaining life, and for showing that these life-sustaining functions are accomplished by body organs functioning together as a system. Points were also awarded for demonstrating an understanding that food and air support vitalist goals. Possible scores range from 0 to 26.[2]

All interviews were scored by two independent coders. Agreement, calculated using the intraclass correlation coefficient, was high (Animism: ICC = 0.98, Death: ICC = 0.82; Body Parts: ICC = 0.84). Disagreements were resolved via discussion.

2.2.3. The executive function battery

This battery included five tasks meant to tap the working memory, inhibition, and shifting aspects of EF.

2.2.3.1. Digits Forward. Digits Forward is a simple verbal memory span test that requires participants to remember strings of numbers of increasing length. Participants are read numbers at a rate of one per second and asked to repeat the numbers back, in order, at the end of each trial. Trials begin at length 2, increasing by 1 after every 2 trials. Testing ends when participants fail both trials of a given length or reach the maximum tested length of 9 digits. The highest span with at least one correct trial is recorded for each participant.

2.2.3.2. Digits Backward. Digits Backward is similar to Digits Forward, except participants must repeat the numbers back in reverse order. This task thus requires both maintenance and manipulation of items in working memory. Participants are given a practice trial at length 3 and then test trials starting at length 2 following the same procedure as Digits Forward. The maximum tested length is 8 digits. The highest span with at least one correct trial is recorded for each participant.

2.2.3.3. Stroop color-word interference test. Participants were administered three conditions of a Stroop task (Delis, Kaplan, & Kramer, 2001). In the baseline condition, participants named the ink color of red, blue, and green squares of ink presented on an 8.5 × 11 in sheet of paper. In the incongruent condition, participants were presented with a display of the words *red, green,* and *blue* presented in an incongruent ink color (e.g., *red* in green ink). Participants were instructed to suppress reading the word and name the ink color. This condition thus requires inhibition. Finally, the switching condition was similar to the incongruent condition, except half the words were presented in black boxes. Participants were told to name the ink color, except when the word appears in a box, in which case they are to read the word. This condition thus measures both inhibition and shifting. In all conditions, there were 10 practice trials and 50 test trials per display. Participants were instructed to complete the task as fast as possible without making errors, and total time was recorded for each condition. The difference score of time to complete the switching condition minus time to complete the baseline condition was computed and used in all analyses.

2.2.3.4. Trail making test (trails). In the baseline condition, participants are presented with a sheet of paper displaying an uneven array of circled numbers (1 through 25). Participants are instructed to connect the numbers with a pencil in ascending numerical order. In the switching condition, participants are presented with a mixed display of numbers and letters and instructed to connect the numbers and letters sequentially, alternating between numbers and letters (e.g., 1-A-2-B). This condition requires shifting (switching between letters and numbers) as well as working memory (keeping track of one's position within the letter and number sequences). In each condition, participants were given 8 practice trials, followed by 25 test trials. Numerals and letters began at 1 and A, respectively. Participants were instructed to complete the task as fast as possible without making errors, and total time was recorded for each condition. The difference score of time to complete the switching condition minus time to complete the baseline condition was computed and used in all analyses.

2.2.3.5. Verbal fluency. In this semantic fluency task, participants are instructed to name as many animals as possible in 60 s without repetition. Strong performance reflects the ability to cluster words into subcategories (e.g., farm animals) and to switch between subcategories when search within a given subcategory is no longer fruitful (Troyer, Moscovitch, & Winocur, 1997). As such, this task measures participants' facility with using abstract representations (subcategories) to facilitate executive control by reducing selection demands, as well as their ability to switch based on endogenous cues rather than the exogenous cues presented in most tests of shifting (Snyder & Munakata, 2010). The total number of animals named minus repetitions and errors was recorded for each participant.

2.2.4. General procedure

Testing occurred during one approximately hour-long session. In line with an individual differences design, testing occurred in the same fixed order for all participants, as follows: MMSE, Animism Interview, Death Interview, Body Parts Interview, Trails, Stroop, Digits Forward, Digits Backward, Verbal Fluency.

[2] Scores on the earlier version of the Body Parts Interview administered to the first eleven elderly participants could range from 0 to 24. Therefore, all Body Parts scores were transformed to percentages prior to data analysis.

3. Results

Data analysis focused first on group differences (young vs. elderly) on each of the three vitalism interviews. First, we sought to directly replicate Zaitchik and Solomon's (2008) finding of worse performance by healthy elderly than the young on the Animism Interview. Second, we sought to test the degradation hypothesis, seeing whether worse performance on the Animism Interview, if observed, would extend to the Death and Body Parts Interviews as well. Anticipating the results, we found that the elderly were indeed worse than the young on the Animism Interview—but only on the Animism Interview. There were no group differences at all on the other two vitalism interviews. For this reason, all subsequent analyses concern the Animism Interview alone. We begin with detailed analyses of the judgment patterns themselves, then go on to the justifications that explicitly articulate the bases of the judgments. Here we aim to discover whether the worse performance of the elderly group derived from interference from agency-based responses. We then turn to performance on the EF battery, analyzing group differences on the EF measures. We present within-group correlations between EF and Animism, asking whether EF predicts performance on Animism within the young and the elderly. Finally, we present mediation and moderation analyses, asking whether variance on the EF measures can account for the difference between the young and the elderly on the Animism Interview and, if it does, in what ways it does so.

3.1. Group differences

We first report the overall performance of the young adults and the elderly adults on the biology battery, asking on which interviews, if any, the young adults outperformed the elderly (see Table 1).

There were no significant group differences on the Death Interview ($t(59) = -1.12$, $p = 0.27$, $d = 0.28$, 95% CI of the difference [−0.98, 0.28]) or the Body Parts Interview ($t(59) = -0.71$, $p = 0.48$, $d = 0.20$, 95% CI of the difference [−0.07, 0.03]). Furthermore, scores of both groups are very high, as is typical of participants with a robust vitalist biology. (The maximum score on the Death Interview is 10, so scores of 7½ to 8 reflect elaborate articulation of a vitalist theory. With respect to the Body Parts Interview, 80% corresponds to an average score of approximately 21 of a possible 26; here too participants articulated high-level vitalist responses.) A close examination of responses confirms the overall quantitative finding. In the Death Interview, when asked what it means to die and what happens when a person dies, both young and elderly participants frequently gave biological responses such as: you are "no longer alive," "your heart stops," "bodily functions stop," and the body "decomposes." Although this interview does not elicit agency responses, it has the potential to elicit religious responses. Indeed, some participants in both groups mentioned cultural and spiritual associations with death, but almost never to the exclusion of vitalist responses. The majority of participants in both groups named people, animals, and plants as things that die. Virtually every subject claimed that death is the end of all bodily or mental functioning and that death is irreversible. In the Body Parts Interview, participants in both groups gave responses such as: the brain is for "thinking" or "controlling body functions," the heart is for "pumping blood (through the body)," lungs are for "breathing" or "providing oxygen," the stomach is for "digestion" or "getting nutrients," and blood is for "carrying oxygen" or "carrying nutrients" "throughout the body." For each internal organ, the majority of participants in both groups correctly responded that without it you would be dead. Finally, the majority of participants in both groups reported that we eat to get "energy" or "nutrients," that we breathe air to get "oxygen," that these substances travel around the body, and that bodily functions depend on the brain. In short, across both of these interviews, young and elderly participants looked very much alike, successfully articulating the framework vitalist theory.

In contrast, analysis of the Animism Interview revealed that the elderly performed significantly worse than the young ($t(59) = 4.70$, $p < 0.001$, $d = 1.20$, 95% CI of the difference [2.25, 5.66]). The range of possible scores on the Animism Interview was −11 to 10, so again, the young group's score of approximately 6½ is close to the high end of the scale.

Healthy elderly adults, when explaining what it means to be alive, perform dramatically differently from the young—even in a condition where they are thinking slowly and deliberately. As expected, their very attributions of life to various entities do not match the canonical vitalist pattern of responses as well as do those of the young (Section 3.1.4; Zaitchik & Solomon, 2008).

Our next analysis looks within the Animism Interview itself, seeking to establish whether lower scores in the elderly reflect agency-based intrusions. Such intrusions might affect not only patterns of attributions of life, but also explicit justifications and elaborations of what it means to be alive.

3.1.1. Animism question 1: What does it mean to be alive, to be a living thing?

Responses to Question 1 were grouped into two broad categories:

(1) Biological: references to biological processes, biological behavior, or biological composition; sample responses: "to be able to breathe," "heart beating."
(2) Agency: references to activity/movement, mental states, social interaction, and goals; sample responses: to "think," "move," "communicate," "doing what makes you happy"

Table 1
Mean scores and standard deviations in parenthesis on the biology interviews as a function of group.

	Young	Elderly
Death	7.58 (1.21)	7.93 (1.26)
Body Parts	0.79 (0.10)	0.81 (0.10)
Animism	6.39 (2.53)	2.43 (3.92)

Note: The Death and Animism scores are average raw scores; the Body Parts scores are proportion correct.

Table 2
Percentage of participants providing biology and agency responses to Question 1.

	Biology	Agency
Young	77.4	41.9
Elderly	73.3	76.7

Table 2 shows that a greater number of elderly than young gave agency-based responses ($\chi^2(1) = 7.60$, $p = 0.006$). It is not the case, however that a smaller number of elderly gave biological responses compared to the young ($\chi^2(1) = 0.14$, $p = 0.71$). This finding is consistent with the finding that the elderly did not differ from the young on the Death and Body Parts Interviews. That is, the elderly are perfectly capable of producing biological responses; indeed, in this they are equal to the young. The group difference lies solely in the number of agency responses produced by the elderly, a far greater number than those produced by the young.

3.1.2. Question 2: Can you name some things that are alive, that are living things?

While every participant mentioned people and/or animals as examples of living things, the elderly were less likely to mention plants (63.3% of elderly compared to 80.6% of young), though this difference did not reach significance ($\chi^2(1) = 2.27$, $p = 0.13$).

3.1.3. Question 3: Can you name some things that are not alive, that are not living things?

The young, compared to the elderly, showed a trend toward more naming of inanimate objects as examples of things that are not alive (Y: 100%, E: 90.0%; $\chi^2(1) = 3.26$, $p = 0.07$). More interesting, however, was the significant difference ($\chi^2(1) = 5.41$, $p = 0.02$) in the rates of naming *dead* people, *dead* animals, or *dead* trees as examples of things that are not alive (Y: 3.2%; E: 23.3%). Such responses, typical of preschool children, reflect the intrusion of the alive/dead contrast on a question that, in older children and young adults, taps the animate/inanimate contrast (Carey, 1985). The finding of significantly more responses of this type among healthy elderly than young adults replicates the same finding reported in Zaitchik and Solomon (2008).

3.1.4. Animism judgments: Is (the object) alive?

The two groups provided markedly different patterns of judgments. The canonical adult vitalist pattern is to attribute life to animals and plants, and not to inanimate objects. Significantly more young adults (87.1%) than elderly (43.3%) provided this canonical pattern ($\chi^2(1) = 12.94$, $p < 0.001$).

A close look at the different patterns of response to the different types of entities—living things (animals, plants), nonliving things (natural kinds, artifacts)—clarifies the judgments of the non-canonical elderly. First, we note that all animals are judged alive by all participants; this makes sense, of course, since both the vitalist theory and the agency theory would categorize them so, albeit for different reasons. This particular finding alone, then, cannot help to identify the underlying basis of the judgment. There were few denials of life to plants in either group (young: 6.5%, elderly: 3.3%). This is also in line with the results on the Death and Body Parts Interviews in suggesting that the elderly maintain their vitalist theory. In contrast, attributions of life to nonliving things strongly indicate judgments based on agency, not vitalist biology, and here the data are clear: the elderly were far more likely than the young to attribute life to inanimate entities. Among the elderly, 53.3% judged at least one inanimate entity to be alive, compared to only 6.5% of the young. It's important to note that those inanimate items that received the most animist attributions from the elderly—the sun (53%), fire (37%), and wind (33%)—are precisely the same items that receive the most animist attributions from young children. These are inanimate entities that are active, moving, and causally powerful.

In summary, the most telling result in the judgments patterns is the elderly's attribution of life to active, moving, and causally powerful but inanimate entities, a pattern reflecting the activation of the agency theory. Next, we turn to the justifications participants gave for their judgments.

3.1.5. Justifications: How do you know that?

Justifications were coded for both biology-based content and agency-based content. Biological justifications referred to biological processes or composition that support life, and/or are constitutive of life: it "breathes", "doesn't grow," "doesn't

reproduce," "needs food," "has cells," and "dies." Additionally, justifications for the natural kind and artifact were coded as biological if participants referred to inorganic origins (e.g., "man made") or inorganic composition (e.g., "made of minerals, metals, glass, which are not alive"), as these contrast with relevant biological processes and composition. Agency-based justifications, in contrast, referenced activity, intentionality, or causal efficacy, such as: it "moves," "thinks," and "can't do anything on its own."

As mentioned above, all participants judged that animals are alive. These *correct* judgments, however, can be justified by appeal to either biology ("it breathes"; "it reproduces") or agency ("it moves"; "it can do things on its own"). If the vitalist understanding is intact in the elderly—but they are more vulnerable than the young to agency-based intrusions—then the elderly should provide roughly the same number of biological justifications as the young, but more agency responses. This is precisely what happened: 93.5% of the young and 86.7% of the elderly provided biological responses, a difference that was not statistically significant ($\chi^2(1) = 0.81$, $p = 0.37$); in contrast, only 51.6% of the young, but 86.7% of the elderly, provided agency responses, a highly significant difference ($\chi^2(1) = 8.74$, $p = 0.003$).

Unlike animals, plants exhibit few overt cues to agency. Therefore, when participants of either age group *correctly* judge that plants are alive, as both groups overwhelmingly do, biological justifications are more likely than agency justifications. Indeed, of those who correctly judged plants to be alive, 82.8% of the young (24/29) and 96.6% of the elderly (28/29) provided biological justifications. This difference was not statistically significant ($\chi^2(1) = 2.97$, $p = 0.09$). As expected, very few agency justifications were given (Y: 6.9%, E: 10.3%). Along with the elderly adults' nearly universal attribution of life to plants, this pattern of responding provides further evidence that the elderly have an intact vitalist biology.

Finally, we turn to the justifications that followed the judgments about inanimate objects (natural kinds and artifacts). In this category, *correct* judgments can be justified by appealing to biology or agency. For example, a correct judgment that a lamp is not alive can be justified by saying that "it's made out of metal" (appealing to its lack of biological composition) or by saying that "it doesn't move" (appealing to its lack of agency). Conversely, incorrect judgments are *more* likely to be justified by agency responses. For example, the *incorrect* judgment that the sun is alive is unlikely to be justified by appealing to its (lack of) biological properties and it is more likely to be justified by appealing to agency (e.g., "it is alive because it heats the earth").

Our first analyses were restricted to participants who correctly denied life to both of the inanimates for which they provided justifications. We found that 86.7% of the young (26/30) and 81.3% of the elderly (13/16) gave a biological response in at least one inanimate justification. Summing across responses to the two justification questions, there was no significant difference between the groups (Mean (SD) number of inanimate justifications containing appeals to biology: Y: 1.43 (0.73), E: 1.25 (0.77); $U = 207.5$, $p = 0.41$). Of these participants, we also found that 36.7% of the young and 68.8% of the elderly appealed to agency on at least one question. Again summing across responses, this difference was significant (Mean (SD) number of inanimate justifications containing appeals to agency: Y: 0.50 (0.73), E: 1.13 (0.89); $U = 146.5$, $p = 0.02$). Thus, we see evidence of agency intrusions selectively among the elderly even in justification for correct denial of life to inanimate objects. As expected, of the 14 elderly who gave a justification for an *incorrect* inanimate judgment, the majority (92.9%) gave agency responses. Of the young adults, only one participant provided justifications for incorrect inanimate judgments, so no further analyses were possible. Thus, when justifying *correct* judgments about nonliving entities, both the young and the elderly relied on biological justifications to a similar extent, but the elderly relied on agency responses to a greater extent than the young. Furthermore, the elderly made far more incorrect judgments (i.e., animist attributions)—and these were explicitly justified by appeal to the entity's agency.

In sum, analyses of the Animism Interview suggest that the elderly perform worse than the young because they are more vulnerable to interference from the agency theory and not because they have lost the vitalist biology. Judgments and justifications for plants are particularly telling in support of this conclusion. Correct attribution of life to plants, living things that are singularly non-agentive, must be based on biology, not agency. The elderly do indeed justify their attributions of life to plants by appeal to vitalist properties of living things such as growth, reproduction, and death. In light of the internal details of the data from the Animism Interview, and in the absence of any group difference on the Death and Body Parts Interviews, there is overwhelming evidence for a problem of elderly participants' deployment, rather than degradation of vitalist understanding, in the generation of judgments and justifications on the Animism Interview that resemble those of young children.

3.2. Executive function battery

Table 3 presents the mean scores and standard deviations on the EF tasks. Correlational analyses over the full sample partialling out age reveal two reliable clusters of tasks: (1) Stroop with Trails ($r(56) = 0.44$, $p = 0.001$); and (2) Digits Forward with Digits Backward ($r(57) = 0.44$, $p = 0.001$). None of the other correlations reached significance. These correlations justify aggregating Stroop and Trails into a composite Shifting/Inhibition (S/I) variable and aggregating Digits Forward and Backward into a composite Working Memory (WM) variable. Aggregates were created by averaging z-scores for each measure. Before creating the composites, missing data points (see Table 3) were replaced with the mean for the group, and reaction time measures were reverse-scored such that, for all measures, higher values indicate better performance. Because Verbal Fluency (VF) did not reliably correlate with other tasks across groups, it was maintained as a separate measure of EF in subsequent analyses. As with the composites, the missing data point was replaced with the mean of the group and fluency scores were converted to z-scores for subsequent analyses.

Table 3
Mean scores and standard deviations in parenthesis for all EF tasks as a function of group.

	Young	Elderly
Digits Forward (raw score)	7.10 (1.22)	6.87 (1.14)
Digits Backward (raw score)	5.58 (1.34)	5.55 (1.48)
WM Composite (z-score)	**0.06 (0.97)**	**−0.07 (1.04)**
Stroop (raw score)	21.83 (11.68)	46.96 (13.83)
Trails (raw score)	24.32 (10.76)	50.30 (39.83)
S/I Composite (z-score)	**0.62 (0.46)**	**−0.64 (1.01)**
Verbal Fluency (z-score)	**0.48 (0.89)**	**−0.50 (0.87)**

Note: All young participants completed every task. Four elderly participants are missing a single data point each due to experimenter error. (These include 1 Digits Backward, 1 Verbal Fluency, and 2 Stroop difference scores.). Higher numbers indicate better performance on Digits Forward, Digits Backward, and Verbal Fluency, but worse performance on Stroop and Trails.

As is evident in Table 3, the difference between the young and the elderly on the working memory composite was not statistically significant ($t(59) = 0.50$, $p = 0.62$, $d = 0.12$, 95% CI of the difference [−0.39, 0.64]). Conversely, the elderly performed poorly compared to the young on Inhibition, Shifting, and Verbal Fluency. This was confirmed by two separate t-tests showing that the elderly performed worse than the young on the Shifting/Inhibition composite ($t(59) = 6.30$, $p < 0.001$, $d = 1.60$, 95% CI of the difference [0.86, 1.66]) and on Verbal Fluency ($t(59) = 4.34$, $p < 0.001$, $d = 1.11$, 95% CI of the difference [0.53, 1.43]).

3.3. Executive function and Animism

We now turn to the relationship between Animism and EF, asking two primary questions: (1) Is the elderly's difficulty in deploying the vitalist biology attributable to declines in EF? and (2) Does EF differentially support deployment of the vitalist biology between groups? This is equivalent to asking whether any of our EF variables either mediate or moderate the group difference on Animism. The two primary questions are complementary. In order for a variable to be a candidate mediator in this case, there must be a group difference on that variable; furthermore, because Group is dichotomous, there must be no interaction between group and the EF variable, as this would preclude a test of mediation (Hayes & Preacher, 2014). We begin exploring these questions by inspecting the within-group correlations.

3.3.1. Within-group correlations

Table 4 presents the bivariate correlations between the three EF measures and Animism as a function of group. Inspection of Table 4 reveals that none of the EF measures were predictive of the Animism score within the young. In stark contrast, every EF measure is significantly correlated with Animism within the elderly. It is possible that the relatively smaller range of Animism scores in the young restricted the possibility to detect a relationship. Indeed, even though there was variability within the young controls, the range of scores was between 1 and 10 points. This means that there were no young controls who showed an overwhelming agency bias. In contrast, the range of scores in the elderly was between −7 and 9. Thus, it is plausible that EF predicts Animism performance as long as the Animism task elicits robust agency intrusions. A relationship between EF measures and Animism scores was not observed in the young, and indeed it could not have been on the above hypothesis, because given the circumstances of this particular study, there were virtually no young individuals who exhibited robust agency intrusions.

In the case of the elderly, who show frequent agency intrusions, significant correlations with all three EF variables is consistent with EF being necessary for expressing a vitalist biology; that is, agency intrusions will appear with ever greater probability the farther EFs drop below some baseline level needed to support consistent expression of vitalist biology. The young, it seems, sit above this level of EF, whereas the elderly are spread around it.

3.3.2. Group by EF interactions

This pattern of correlations only points toward the possibility that EF moderates the relationship between Group and Animism. A test for an interaction of Group and WM as predictors of Animism scores revealed that the interaction was trending ($\Delta R^2 = 0.04$, $F(1,57) = 3.90$, $p = 0.053$). Thus, the effect of WM is different across different levels of Group. Whereas the young with low WM scores and the young with high WM scores performed at a similar level on Animism, the elderly with high WM scored higher on Animism than those with low WM. It is important to emphasize, however, that the difference between the young and the elderly on WM was not statistically significant, which means that WM cannot statistically account for the group difference on Animism. Nevertheless, the Group × WM interaction points out that WM may serve a compensatory role in supporting performance in the elderly, compensating for whatever factors lead to worse performance of this group on Animism.

Table 4
Bivariate correlations between EF and Animism as a function of group.

	Young	Elderly
	Animism	
WM Composite	0.092 ($p = 0.62$)	0.48 ($p = 0.008$)
S/I Composite	−0.009 ($p = 0.96$)	0.42 ($p = 0.02$)
Verbal Fluency	−0.063 ($p = 0.74$)	0.44 ($p = 0.01$)

VF and S/I are different from WM in one very important way. Namely, the young performed over 1 standard deviation higher than the elderly on both VF and S/I (see Table 3). This means that these two variables can potentially account, statistically, for why the elderly performed worse than the young on Animism. If performance on Animism is related to S/I and VF, then scoring extremely low on these variables will mean scoring extremely low on Animism as well; if only the elderly score extremely low on VF and S/I, then they will be the ones who score extremely low on Animism. As foreshadowed by the correlations presented above, a test for an interaction of Group and VF as predictors of Animism scores revealed a significant interaction effect ($\Delta R^2 = 0.06$, $F(1,57) = 5.61$, $p = 0.02$). Thus, the effect of VF is different across different levels of Group. Whereas VF is not related to Animism within the young, it is within the elderly: that is, those with lower VF perform worse. By implication, the difference between the two groups is biggest among those who score low on VF, most likely because the elderly's low scores on VF were much lower than the young's low scores on VF. Taken together, the elderly's poor performance on VF and the association between VF and Animism within the elderly is consistent with the hypothesis that the elderly's agency intrusions are strongly associated with declines in their executive functioning.

Finally, despite the finding that S/I was correlated with Animism only within the elderly, the Group x S/I interaction was not significant ($\Delta R^2 = 0.02$, $F(1,57) = 1.46$, $p = 0.23$).[3] The lack of significant interaction allowed us to ask whether the group difference on Animism is mediated by S/I, which is to ask whether the group difference on Animism is attributable to the difference in S/I scores. Mediation analyses were conducted using the MEDIATE macro for SPSS (Hayes & Preacher, 2014).

3.3.3. Mediation analysis: Shifting/Inhibition

The mediation analysis (Fig. 1) indicates that S/I significantly mediates the effect of group on Animism ($a * b$ (indirect effect) = −1.67, 95% CI [−2.84, −0.51]). A decrement of 1.67 on Animism for the elderly compared to the young is attributable to their decreased Shifting/Inhibition. The remaining direct effect of group on Animism—that is, the effect not attributable to S/I—is still significant (c' (direct effect) = −2.28, $t(58) = -2.19$, $p = 0.03$), suggesting that additional factors also contribute to the group difference.

As established above, one potential additional contributor to the group difference is VF performance. Indeed, VF accounts for some of the remaining direct effect found in the S/I mediation analysis presented above (Fig. 1). Including VF as a covariate in the mediation analysis with S/I, the indirect effect of S/I on Animism remains significant ($a * b = -1.56$, 95% CI [−2.72, −0.66]), while the direct effect is reduced and no longer significant ($c' = -1.55$, $t(57) = -1.40$, $p = 0.17$). In sum, the young almost uniformly score higher on S/I compared to the elderly and they also score higher on Animism. However, when S/I is accounted for, the difference between the young and the elderly on Animism is significantly reduced, and when both S/I and VF are accounted for, the young and the elderly no longer look different on Animism. This is consistent with the hypothesis that executive functions are needed for the successful deployment of vitalist biology, and especially for the successful resistance to agency intrusions.

4. General discussion

Elderly adults—even those rigorously screened to be free of cognitive deficit—sometimes show impairments on tasks that tap conceptual understanding. The present study provided dramatic confirmation of this phenomenon in the case of healthy elderly participants' conceptual understanding of life. Here we highlight two singular contributions of the present study to the understanding of such impairments in causal-explanatory reasoning. First, by analyzing patterns of conceptual impairments across tasks that tap different aspects of the same theory, we have developed a research strategy to distinguish degradation accounts of such impairments from deployment accounts. Applying this strategy to the domain of vitalist biology, we show that the elderly suffer from difficulties deploying the theory, and not from semantic degradation of the theory. Second, we begin to identify domain general mechanisms that may underlie deployment difficulties, finding in this case that they are mediated and moderated by declines in shifting and inhibitory processes among the elderly.

4.1. Degradation, deployment, and high-level conceptual reasoning

The first goal of this study was to explore whether the reemergence of childhood animism in the elderly is the result of semantic *degradation* of the vitalist theory—a finding consistent with neuropsychologists' claim that the domain of living

[3] It is possible that with a larger sample size the Group x S/I interaction would be significant. Were that the case it would change the interpretation of the role of S/I from mediator to moderator but would still demonstrate an association between S/I and diminished performance on Animism among the elderly.

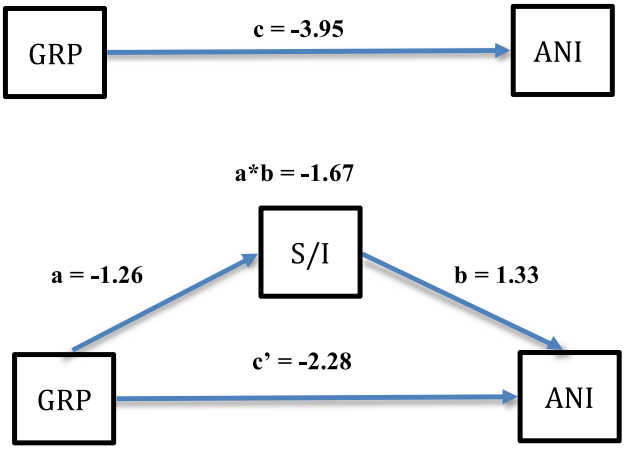

Fig. 1. Mediation model of the effect of Group on Animism through S/I. Top: the total effect of Group on Animism (i.e. the group difference). Bottom: the mediation model. The indirect effect of Group via S/I is found by multiplying the two paths that connect Group to Animism via S/I (a * b). The remaining direct effect (c') represents the effect of Group after partialling out the effect of the mediator.

things is especially vulnerable to semantic degradation (see Section 1)—or whether the difficulty is solely one of deploying the theory. Given that the vitalist biology is an integrated system of representation, a *coherent* theory, any degradation should be reflected in the understanding of death and bodily function as well as in distinguishing living from non-living entities. Here our finding is unequivocal: the reemergence of animist judgments in the elderly reflect difficulty only in *deploying* the theory. Among the vitalist biology tasks, the Animism Interview—and only the Animism Interview—showed worse performance with age. Moreover, within the Animism Interview, as well as in the Death and Body Parts Interviews, both the elderly and young succeeded equally at articulating the vitalist theory.

The *nature* of the deployment difficulty in the elderly is also clear in the data: the elderly are far more vulnerable than the young to interference from prepotent responses generated by the agency construal of life. Crucially, this interference goes beyond errors of naming or retrieval found in the patient literature (Whatmough & Chertkow, 2002), and it further goes beyond simple errors in semantic judgments such as those found under speed (Goldberg & Thompson-Schill, 2009). The Animism justifications make this clear—the elderly who made animist judgments explicitly justified their judgments with reference to properties of causal agents. Recall that our participants were not under cognitive load, and were not required to answer quickly; rather, they were probed to reflect upon and articulate their understanding of life, death, and the bodily machine. The elderly's deployment difficulties, then, are not isolated low-level phenomena. In accord with framework theories' role in structuring conceptual content, impairments in utilizing these theories—either due to degradation or deployment—are expected to reverberate through inference and reasoning. This is exactly what we find here. Concretely, being unable to access the semantic knowledge that a zebra has stripes will only impair judgments and reasoning that concern this one particular fact about zebras. On the other hand, an agency-based concept of *life* contributes to the articulation of an entirely different intuitive theory of living things than a vitalist-based concept of *life,* one that is in fact incommensurate with the vitalist theory (Carey, 1985; Johnson & Carey, 1998). Accessing the former conceptual structure rather than the latter, as our elderly adults do, entails the use of an entirely different framework of reasoning and inference concerning the essential properties of animals and other living things. This agency-based framework identifies activity, movement, and causal power—as opposed to biological properties—as the causally deepest and inferentially richest core features of animals.

Given the incommensurability of the theories, one might wonder why agency intrusions do not arise in the Body Parts or Death Interviews. There are two reasons for this. First, those interviews tap core features of vitalist theory other than the distinction between animates and inanimates. Both Death and Body Parts focus on the role of the body in maintaining life, and the interrelations between bodily function, life, and death. That is, both concern living things alone; inanimate objects do not even come up in these interviews. Second, from the point of view of these aspects of vitalism, agency (in the sense of activity) is an explananda of the theory—vital energy derived from food and air is transformed by the body into the capacity for movement and action. Thus, in these contexts, appeals to agency need not be inhibited, for along with the capacity for growth, health, and the maintenance of life, the capacity for activity is in the domain of the theory. Still, an open question for future research is the degree to which elderly adults might notice potential discrepancies in their reasoning stemming from the use of two different theories.

4.2. Executive function and Animism

The second goal of the study was to probe potential mechanisms in normal aging that leave healthy elderly adults vulnerable to difficulty deploying conceptual knowledge. Given that the Animism task appears to draw heavily on inhibition, we explored the consequences of age-related decreases in EF for the deployment of theoretical, explanatory knowledge.

4.2.1. Shifting/Inhibition

This EF component partially mediated the group effect on Animism. Moreover, within the elderly group, higher S/I scores predicted significantly better performance, reflecting a greater proportion of biological responses over agency responses. The most likely interpretation of this finding is that shifting and inhibitory processes are needed to suppress agency-based responses and/or to select and maintain the proper task set in the face of alternative construals of animals.

4.2.2. Verbal Fluency

As noted above (Section 3.3.2), the Group x VF interaction is driven by the relatively strong relationship between Animism and VF in the elderly as compared to the young. This interaction may be the result of a compensatory process that is needed by the elderly, but not by the young. VF has been shown to activate a region of ventrolateral prefrontal cortex associated with "postretrieval selection" among competing representations (Badre & Wagner, 2007; Hirshorn & Thompson-Schill, 2006). Given their reduced ability to inhibit the activation of the salient agency representation to begin with, the elderly may need to draw more heavily on this postretrieval selection mechanism in order to choose biological over agency-based responses because both will be active in working memory. Supporting this idea is the finding that elderly adults performing a Stroop task show decreased activity, compared to young adults, in dorsolateral prefrontal areas associated with inhibition, working memory, and the control of attention. At the same time, however, they show increased activity in ventrolateral prefrontal areas (Milham et al., 2002). These findings suggest that older adults are compromised in their ability to bias the contents of working memory toward task relevant representations, necessitating compensatory selection processes in order to succeed.

VF has also been taken as a measure of endogenous (self-driven) flexibility or shifting, as opposed to the exogenous (task-cued) shifting of Stroop and Trails (Snyder & Munakata, 2010). Endogenous flexibility appears to make different demands than exogenous flexibility (e.g., greater metacognitive awareness of when to switch). It makes sense then that endogenous flexibility would be necessary on the Animism Interview, which contains no explicit cues about which meaning of *alive* is appropriate.

4.2.3. Working Memory

It is surprising that we found no group differences in WM in our sample, given findings of age-related decline on similar span tasks in other studies (Foos, 1989; Grégoire & Van der Linden, 1997). Education may have played a factor in these results. Our elderly group was highly educated overall, and some studies have found education to better predict WM performance on span tasks than does age (e.g., Dobbs & Rule, 1989). Our WM composite tapped both the short-term memory (Digits Forward) and the executive (Digits Backward) components of working memory (Gathercole, Pickering, Ambridge, & Wearing, 2004; Oberauer, Süß, Schulze, Wilhelm, & Wittmann, 2000; cf. Engle, Tuholski, Laughlin, & Conway, 1999). While a more difficult battery of WM tasks focusing exclusively on the executive component may have revealed a group difference on WM, our composite successfully predicted Animism scores within the elderly. Again, this is consistent with a role for executive processes in maintaining and manipulating information in order to facilitate task relevant processing; in this case, such processing involves maintaining information about the biological context of the task to inform responding.

4.3. Young adults

Finally, the lack of significant statistical relations between measures of EF and Animism scores in the young does not necessarily indicate the absence of such a relationship. More likely, as shown by their strong performance on both the biology and the EF tasks, this sample suffered from restriction of range in detecting such effects. Larger samples with more difficult measures of EF, and Animism measure taken under cognitive load (e.g., the speeded conditions of Goldberg & Thompson-Schill, 2009)—might establish the continuity of this relationship across the life span. Additionally, studies examining the time course of the relationship between EF and Animism from middle age to late old age may be better suited to discovery of the exact nature of the relationship, as this period better captures the decline in EF during aging (Borella et al., 2008).

Alternatively, the lack of significant associations between EF and Animism in young adults may reflect robust differences between the two groups. For example, in a study in which inhibition was demanded on one task but not a following task, the suppression of the previously inhibited information from the first task carried over into the second task in young but not elderly adults (Healey, Ngo, & Hasher, 2013). In short, suppressed information remains suppressed far longer in the young than in the elderly. In relation to the Animism Interview, which demands the constant inhibition of prepotent agency responses, the relative lack of sustained inhibition in the elderly may leave them more open to agency-based interference throughout the interview. The young, in contrast, may suffer far less interference because they continue throughout the task to benefit from any inhibition of agency representations exercised early in the interview. If such sustained suppression does not rely on active EF processes, this may be one reason for the lack of associations between EF and Animism in the young adults.

4.4. Relationships to theories of cognitive aging

This study presupposed that a decline in inhibitory mechanisms—mechanisms responsible for gating access to working memory, removing information from working memory, and inhibiting prepotent responses—is a central deficit

accompanying normal aging (Hasher & Zacks, 1988; Lustig, Hasher, & Zacks, 2007). Indeed, there is evidence that difficulty inhibiting distractors or filtering information can lead elderly adults to in fact hold *more* information in working memory than young adults (Hasher & Zacks, 1988; Lustig et al., 2007). This is consistent with our finding of similar levels of biological responding—and much greater agency-based responding—among the elderly, compared to the young.

Our findings are also consistent with other proposals concerning central cognitive declines with aging. Another view of the core executive deficit in aging is that its locus is in "context processing" (Braver et al., 2001), where context includes goals, cues, and other information actively maintained in the service of task performance. For example, elderly adults perform worse than young adults when a prior cue facilitates preparation of the correct response; they perform better than young adults when a prior cue interferes with making the correct response (Braver et al., 2001). Presumably, in both cases, the elderly are less able to maintain the cue, so it has a weaker effect on the elderly than the young. This leads to worse performance when the cue is facilitating and to better performance when it is interfering. From this perspective, we might interpret the deficits of the elderly on the Animism Interview as a failure to identify and/or maintain the cue—in this case the biological context of the task—in order to bias responding toward biological answers throughout the interview.

4.5. Concluding remarks

The present results are the first to show that declines in EF may affect deployment of theoretical knowledge in healthy elderly adults. It is unsurprising that the elderly, like young adults and even young children, deploy theories to understand their world. This may be a signature property of our species. The elderly, however, provide a unique lens from which to view the relationship between domain-general cognitive mechanisms and deployment of domain-specific knowledge. Like young children in terms of their relatively weak EFs (compared to young adults), they nevertheless differ from children in terms of their hold on the biological theory. While children are yet to construct the vitalist biology, the elderly must only deploy it. Like young adults in terms of their strong command of the vitalist theory, the elderly are unlike young adults in having weaker EFs. Given the differences in their profile from both children and young adults, studies of the elderly allow us to assess the effects of EF on deployment of specific theories in adults without the need for experimental manipulation of EF.

While our earlier studies revealed animist reasoning in the elderly (Zaitchik & Solomon, 2008), the present study reveals the source of this immature reasoning: interference from the agency theory in the *deployment* of vitalist biology. As noted above, elderly adults have held the vitalist theory several decades longer than have the young, yet they are more prone to agency-based errors rather than less prone. This finding provides strong evidence that old theories—especially old theories that may be useful in some contexts—remain in the conceptual system. Representations activated by our immature childhood theories (Shtulman & Valcarel, 2012) or by explanatory defaults prevalent in childhood (Lombrozo et al., 2007) may therefore remain a continual source of conceptual conflict in adulthood. In the present case, the difference with age is not in the theory held. It is in the ability to deploy the theory in the face of interference from the earlier developing theoretical construal of animals as intentional and causal agents.

The present study investigates the role of EFs in managing the conflict between the agency theory and vitalist biology. Our findings confirm a role for multiple executive processes, though there may be additional mechanisms at play here as well. It will clearly take further investigation to provide a comprehensive understanding of the domain-general cognitive processes underlying theory deployment as we age as well as to characterize the full extent of the downstream consequences of deployment difficulties on reasoning and inference. Finally, the regressive phenomena with which we began this paper (Piagetian conservations, intuitions about species transformations, promiscuous teleology, theory of mind, moral reasoning, childhood animism) are less apparent in healthy elderly than in populations with diseases of aging such as AD. It is still very much open whether the actual diseases of aging involve degradation of those aspects of semantic memory that structure our conceptual system—our framework theories—or whether they also reflect problems in deployment of conceptual knowledge alone. The answer could well be different in such cases from that found here. A high priority of future research is to apply the analytic strategy developed here to explore these hypotheses in populations with AD and other brain diseases.

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Appendix A. Biology interviews with detailed scoring criteria

A.1. The Animism Interview

Q1: What does it mean to be alive?

2 points: Biological processes (*growth, death, life cycle)* or biologically relevant behavior (*breathing, eating*)

−2 points: Agency based responses, including activity/movement/goal-directed movement, mental states, communication/social interaction, things that give life meaning/the meaning of life

0 points: All other responses

Q2: Can you name some things that are alive, that are living things?
2 points: People, plants, animals, either in general or specific examples
1 point: People and/or animals but not plants
0 point: Don't know, lack of response
−1 point for any inanimate object
Q3: Can you name some things that are not alive?
2 points: Any inanimate object
1 point: Dead people, dead animals, or dead plants; dinosaurs or extinct animals
0 points: Don't know, lack of response
−1 point for imaginary entities
−1 points for animals or plants
Yes/No Judgments: Is an x alive?
−3 points: Yes to all animals and one or more artifacts.
−2 points: Yes to all animals and one or more natural phenomena; no to artifacts
−1 point: Yes to all animals, no to one/both plants, natural phenomena, and artifacts
0 points: Yes to all animals and both plants; no to natural phenomena and artifacts
Justifications: You said that an x is/is not alive. How do you know?
1 point: For the animal and plant, a biological response (bodily processes, requirements, or relevant internal body parts) e.g. "a cat is alive because it breathes".
For the natural kind, lack of biological function or inorganic composition (e.g., "wind is moving air particles.")
For the artifact, inorganic origin or composition, e.g. a lamp is not alive because people made it."
−1 point: Agency based responses, including activity/movement, energy, mental states, communication/social interaction
0 points: All other responses

Points were summed according to the point values above to create a composite Animism score. Points assigned positive values reflect biological responding and points assigned negative values represent agency-based responding (or in the case of Q2 and Q3 responding based on the real-imaginary distinction rather than the alive-dead distinction). Question 1 and the Justifications were scored separately for biology and agency, e.g. someone who responded to Question 1 with "breathing and walking" would receive 2 points for Biology and −2 points for Agency, for a total score of 0 on that question.

A.2. The Death Interview

Q1: What does it mean to die?
Q3: What happens to a person when they die?
Q4: What happens to a person's body when they die?
With respect to the following properties, responses to questions 1, 3 and 4 were considered as a single response: possible score of 3
1 point for each of the following: (a) Breakdown of bodily function (e.g. "stop breathing"), (b) decomposition (e.g. "body rots"), or (c) death as end of life (e.g. "not alive *anymore*")
0 points: Behavioral responses, burial, religious interpretations of death, or death as opposite as life (e.g. "not alive")
In addition:
−1 point for religious responses only e.g.("go to heaven") to Question 4.
Q2: Can you name some things that die?
Points are summed as follows:
2 points: All living things must eventually die
1 point: People and/or animals, either generally or specific examples.
1 point: Plants, either generally or specific examples
0 points: Someone or something that is already dead (e.g. "George Washington"); dinosaurs or extinct animals
−1 point: imaginary entities
−1 point: Inanimate objects
When someone is dead, do they need to eat/pee/sleep?
−1 point for each yes or don't know response, or, for sleep, "no because they're already asleep"
When someone is dead, do they feel bad/miss their friends/think about things?
−1 point for each yes or don't know response, unless it is mentioned in reference to the soul and not the body.
What might cause someone to die?
3 points: Cessation of biological function (e.g. "their heart stops beating")
2 points: Illness or old age
1 point: Specific avoidable cause (e.g. "getting shot")
Does every person die?
1 point: Yes
0 points: Don't know
−1 point: No

Is there anything anyone could do to make a dead person live again? Could a doctor make a dead person live again?

1 point: No to both questions or No to first question followed by Yes to the second question only if justified by reference to defibrillation ("a zapper")

0 points: Don't know

−1 point: Yes to both questions or No to the first question followed by Yes to the second question.

Points summed to create a composite score for the Death Interview.

A.3. The Body Parts Interview

Data regarding hands, eyes, and location of body organs were not coded as they were irrelevant to hypotheses. Scoring for internal body parts was as follows:

What is it for? What happens if you don't have one?

2 points: Relating the organ's function to another bodily function/explaining how the specific function they identify supports a biological goal.

1 point: One organ-one function (e.g. "the brain is for thinking")

0 points: Don't know, lack of response, non-biological function (e.g. "the lungs are for talking")

For each organ, 1 additional point was given for mentioning the organ is needed to stay alive.

Why do we eat food?

2 points: Specific biological response: energy, nutrients, growth, nourishment

1 point: Nonspecific biological response: strength, health, life

0 points: Psychological response (e.g., "we're hungry"), don't know, lack of response

What happens to the food we eat?

3 points: Biological response relating food to the functioning of the body (e.g., "heart passes needed food to parts of body that need it")

2 points: Other biological response (e.g. "it becomes poop", "it gets digested")

1 point: Purely mechanical response (e.g. "it goes into the stomach" or "it gets mushed up")

0 points: Don't know, lack of response

Do you need a brain to be able to eat?

1 point: Yes

0 points: No

Why do we breathe air?

2 points: Biological response (e.g. "to bring in oxygen")

1 point: Behavioral response (e.g. "to talk") or response not specific to organ (e.g. "to live")

0 points: Don't know, lack of response

What happens to the air we breathe?

2 points: Biological response (e.g. "air changes food to energy")

1 point: Purely mechanical response (e.g. "it goes in and out")

0 points: Don't know, lack of response

Do you need a brain to be able to breathe?

1 point: Yes

0 points: No

Points summed to create a composite score for the Body Parts Interview.

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