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Research Article

Knowing "what for," but not "where": Dissociation between functional and contextual tool knowledge in healthy individuals and patients with dementia

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Abstract

Objective: Semantic tool knowledge underlies the ability to perform activities of daily living. Models of apraxia have emphasized the role of functional knowledge about the action performed with tools (e.g., a hammer and a mallet allow a "hammering" action), and contextual knowledge informing individuals about where to find tools in the social space (e.g., a hammer and a mallet can be found in a workshop). The goal of this study was to test whether contextual or functional knowledge, would be central in the organization of tool knowledge. It was assumed that contextual knowledge would be more salient than functional knowledge for healthy controls and that patients with dementia would show impaired contextual knowledge. **Methods:** We created an original, open-ended categorization task with ambiguity, in which the same familiar tools could be matched on either contextual or functional criteria. **Results:** In our findings, healthy controls prioritized a contextual, over a functional criterion. Patients with dementia had normal visual categorization skills (as demonstrated by an original picture categorization task), yet they made less contextual, but more functional associations than healthy controls. **Conclusion:** The findings support a dissociation between functional knowledge ("what for") on the one hand, and contextual knowledge ("where") on the other hand. While functional knowledge may be distributed across semantic and action-related factors, contextual knowledge may actually be the name of higher-order social norms applied to tool knowledge. These findings may encourage researchers to test both functional and contextual knowledge to diagnose semantic deficits and to use open-ended categorization tests.

Keywords: activities of daily living; apraxia; tool use; semantic knowledge; dementia; Alzheimer's disease

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Introduction

Impairment of activities of daily living (ADL) is a core diagnostic criterion for neurodegenerative diseases (e.g., McKhann et al., 2011). It is generally assessed with self-report, informant-based questionnaires evaluating basic (e.g., *eating*) and instrumental ADL (e.g., *meal preparation*; Mioshi et al., 2007), and simulated activities of daily living (S-ADL; e.g., Schwartz et al., 2002). S-ADL requires patients to select and use tools to perform multi-step, nested action sequences (e.g., having lunch implies both to prepare a meal and to set the table; for a review, see Giovannetti et al., 2021). Naturalistic action deficits have been documented in patients with unspecified mild-to-moderate dementia (Giovannetti et al., 2002), Alzheimer's disease and vascular dementia (Giovannetti et al., 2006, 2008; Jarry et al., 2021), and stroke patients with semantic impairments (Corbett et al., 2009; see also Foundas et al., 1995). Similar tasks have been used in apraxia studies. Apraxia of tool use (hereafter referred to as apraxia) is the inability to use familiar or novel tools properly following brain lesions, in the absence of elementary sensorimotor, coordination, comprehension, or attentional deficits (Geschwind, 1975; Rothi et al., 1991, 1997). Patients may have difficulties selecting or manipulating familiar tools (Buchmann & Randerath, 2017; Goldenberg & Hagmann, 1998; see also Osiurak et al., 2018). Like naturalistic action impairments, apraxia has been described in patients with Alzheimer's disease or semantic dementia (Baumard et al., 2016; Bier et al., 2013; Bozeat et al., 2000, 2002; Buchmann et al., 2020; Dumont et al., 2000; Lesourd et al., 2013, 2017; Schwartz et al., 2000). Semantic dementia is a rare focal cortical atrophy syndrome arising from temporal lobe lesions, and characterized by loss of conceptual knowledge responsible for deficits in naming, word meaning

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comprehension, and identification of objects and persons (Bozeat et al., 2000; Neary et al., 1998; Snowden et al., 2018). Functional disability has been associated with institutionalization (Knopman et al., 1988) and caregiver burden (Debettignies et al., 1990). Understanding the cognitive underpinnings of S-ADL and tool use is therefore a critical issue, especially since neuropsychologists are frequently asked to predict the ability of patients to live at home.

The ability to perform S-ADL tasks is the result of a multifaceted process (Baumard et al., 2014; Baumard & Le Gall, 2021; Canzano et al., 2016). The dementia literature has emphasized the role of episodic memory and executive functioning (see the "omission-commission model," Giovannetti et al., 2008). Because of these impairments, patients may lose track of action goals, or conflicting task goals may be activated in a disorderly fashion, resulting in errors (see the "goal-control model," Giovannetti et al., 2021). Patients' performance may be very sensitive to how tools are presented (e.g., prearranging the tools or letting the patient doing so), and the presence of distractors functionally and visually similar to the target objects may hamper tool selection (e.g., salt/sugar; Brennan et al., 2009; Giovannetti et al., 2007, 2010). These works have strongly suggested that the tool selection phase of S-ADL completion is a problem for patients with dementia, while the reason for this remains unclear. The literature on apraxia has attached great importance to the role of semantic tool knowledge.

Categorization and semantic tool knowledge

Semantic tool knowledge underlies the ability to use familiar tools and objects in a prototypical manner (Lesourd et al., 2021; Roy & Square, 1985; Stamenova et al., 2012). It has also been proposed to inform individuals about the context in which they can find tools (Osiurak, 2014). Semantic tool knowledge allows individuals to perform categorization tasks in which they are asked whether two tools share some characteristics. Categorization is the operation by which individuals notice that objects tend to cluster, in terms of their physical or linguistic attributes, or with regard to their functional significance for adaptive behavior (Anderson, 1991). In an ecological setting, this allows individuals to perceive a rational structure in the world, instead of a virtually infinite number of equiprobable, cooccurring tool attributes (Rosch, 1988).

Semantic memory is hierarchically organized along subordinate (e.g., Labrador), basic (e.g., dog), and superordinate levels (e.g., animal; Rosch & Lloyd, 1978). Three superordinate categories have received particular attention: taxonomic knowledge, functional knowledge, and contextual knowledge. The taxonomic semantic system stores knowledge based on (mainly visuoperceptual) similarity and allows individuals to consider different items as "the same" or similar items. This system underlies visual, basic-level categorization, which is the less abstract form of categorization. It consists in deciding whether two tools share some visual commonalities, like shape for example (e.g., both a hammer and a screwdriver have a handle; Rosch, 1988; for a review, see Estes et al., 2011). Functional relations are based on shared features of tools (tools that are alike) whereas contextual relations are based on space and time contiguity (tools that are used in the same space-time event; Lesourd et al., 2021). Functional and contextual knowledge are sometimes grouped into a broad "thematic" or "contextual-functional" category (e.g., Merck et al., 2014), yet there is no consensus as to which categorization criteria should fall into this scope (see Estes et al., 2011). In patients with semantic dementia, dissociations have been documented between visual features and contextual-functional features (Merck et al., 2014, 2019). For example, Merck et al. (2019) documented a semantic priming effect for thematic relationships (e.g., squirrel-hazelnut) but not for perceptual relationships (e.g., cat-whiskers) in patients with semantic dementia while healthy controls showed the reverse pattern. Yet, these studies did not make a distinction between functional and contextual criteria, and they mixed biological concepts and man-made artifacts and hence did not focus on tool knowledge specifically.

There are currently two views in the apraxia literature. Classical models of apraxia are structured around functional knowledge, which may be critical to retrieve the prototypical function of tools (e.g., a brush allows a "tracing" action; Roy & Square, 1985; Stamenova et al., 2012). Models of tool use like the Four Constraints Theory (4CT; Osiurak, 2014) have rather insisted on the role of contextual knowledge. The 4CT has assumed that the ability to use familiar tools depends on semantic reasoning, namely, the ability to make hypotheses as to where one may find tools she/he needs to perform a specific action. For example, tools for a "cutting" action (e.g., a sharp, rigid tool) may be found in the garage, workshop, or supermarket. So, in this view, contextual, but not functional knowledge, is critical to perform activities of daily living.

Brain networks of semantic tool knowledge

Patients with neurodegenerative diseases may demonstrate impairments of semantic cognition (Bozeat et al., 2000; Hodges, 2000) as well as difficulties to use tools (Giovannetti et al., 2002, 2006; Jarry et al., 2021; Lesourd et al., 2013). Therefore, neurocognitive accounts of tool use and semantic memory have attempted to explain how tools are represented in the brain. Tool use depends critically on the left inferior parietal gyrus, the intraparietal sulcus, and the lateral occipitotemporal cortex (Buxbaum et al., 2014; Goldenberg & Spatt, 2009; Goldenberg, 2009; Kalénine et al., 2010; Kalénine & Buxbaum, 2016; Reynaud et al., 2016). Errors in S-ADL tasks have been associated with the volume of the medial temporal lobes, with the hippocampus being critical to sustaining goal activation during task completion (for a review, see Giovannetti et al., 2021). In contrast, semantic knowledge depends strongly on the anterior temporal lobes (Jefferies et al., 2020; Lambon Ralph et al., 2017; Schwartz et al., 2011). Taxonomic processing activates the bilateral visual areas as well as the anterior temporal lobes, whereas thematic processing activates a bilateral temporoparietal network including the angular gyrus, and the posterior middle temporal gyrus (Kalénine et al., 2009; Schwartz et al., 2011).

In the framework of the Controlled Semantic Cognition and Hub-and-spoke model (Lambon Ralph et al., 2017), the anterior temporal lobes have been proposed to store abstract, cross-modal tool representations, while the inferior frontal gyrus, the angular gyrus and the posterior middle temporal gyrus may be critical to control semantic activations with regard to task goals. Patients with disorders of semantic control do not show semantic memory loss, yet they may have difficulties in using knowledge in context. As a result, they may show poor performance on executively-demanding tasks, poor inhibition of competitors, inconsistent performance across tests, and poor performance in ambiguous tasks requiring them to select a response among several potentially correct options.

Table 1. Demographic and neuropsychological variables

	Max. score	Healthy controls	Patients w/ dementia	Alzheimer's disease	Semantic dementia
Demographic variables					
N	–	20	30	20	10
Age	–	68.9 (7.8)	72.0 (7.9)	74.8 (6.3)	66.5 (8.1)
Education (years)	–	11.7 (4.5)	9.5 (3.8)	8.5 (4.0)	11.5 (2.4)
Gender (F/M)	–	14 / 6	19 / 11	14 / 6	5 / 5
Neuropsychological variables					
MMSE	30	28.2 (1.8)	**21.3 (2.8)**[a]	20.4 (2.1)	24.7 (2.7)
General cognition (BEC)	96	90.5 (3.3)	**67.6 (6.9)**[a]	67.5 (6.1)	68.3 (9.9)
Recall of words	12	11.3 (0.9)	**6.7 (2.3)**[a]	6.8 (2.3)	6.5 (2.6)
Recall of pictures	12	10.7 (1.1)	**6.7 (2.7)**[a]	5.7 (1.9)	10.2 (1.8)
Category fluency	12	11.9 (0.7)	**9.0 (2.9)**[a]	9.8 (2.6)	6.5 (2.5)
Picture naming	12	11.5 (0.7)	**8.9 (2.8)**[a]	10.0 (1.9)	5.6 (2.8)
Functional knowledge	10	9.1 (0.9)	7.4 (2.6)	7.8 (2.3)	6.8 (3.1)
Contextual knowledge	10	9.7 (0.7)	**7.6 (2.1)**	7.9 (1.8)	7.1 (2.6)
Pantomime of tool use	20	17.9 (2.0)	**14.8 (4.2)**	14.9 (4.6)	14.6 (3.5)
Activities of daily living	16	13.8 (1.7)	**8.2 (4.2)**	8.1 (3.5)	8.6 (5.7)

Patients with dementia corresponds to the whole group of patients with either Alzheimer's disease or semantic dementia. Values are mean values except for gender. Values between brackets are standard deviations. Bold values are significant control-patient differences (Chi-square tests or Mann-Whitney U tests with $p < .05$).
[a]$N = 4$ missing data due to comprehension deficits, depressive symptoms, or scheduling issues. The BEC questionnaire assesses working memory, time and space orientation, elementary mathematical cognition, proverb comprehension, similarities, verbal semantic fluency, naming, visual and verbal episodic memory, and visuoconstruction.

Clinical and experimental tasks

In classical semantic tests, patients are presented with pictures or photographs of tools, and instructed to choose the two that share some characteristics. In functional matching tasks, patients have to match tools that share the same function or goal (e.g., a hammer and a mallet both allow a "hammering" action; Bartolo et al., 2007; Buxbaum & Saffran, 2002; Kalénine & Buxbaum, 2016). In contextual matching tasks, patients have to match tools with their usual context of use (e.g., hammer/workshop; Baumard et al., 2016; Osiurak, 2014; Perini et al., 2014). The ecological value of these tests remains questionable because they are very structured (there is only one possible choice) and make the target highly salient (e.g., hammer goes with nail, not with shoe). There is more ambiguity in an ecological setting, where a given tool may activate competing tool representations at the same time. So, in activities of daily living individuals have to hierarchize all the possible semantic criteria, and select the one that is most relevant to the task at hand (hereafter referred to as "the preferred criterion"). Previous research has focused on patients' errors in the execution of S-ADL tasks (e.g., Giovannetti et al., 2008, 2021). However, before performing the action sequence and manipulating tools, it is necessary to infer which tools belong to which action-goal categories, especially when multiple activities are possible at the same time (e.g., [Water-coffee-coffee machine-coffee pot-spoon] for the goal "making coffee"). In the framework of the Controlled Semantic Cognition (Ralph et al., 2017), this likely increases the loads on semantic control. In this regard, it is necessary to study the performance of patients with categorization tasks that mirror the needs of S-ADL tasks (i.e., multiple possible criteria, large number of tools presented simultaneously).

The present study

In the present paper, it is proposed that performing S-ADL tasks calls for semantic tool knowledge and categorization because individuals need to understand which tools go together even before manipulating them. It was assumed that contextual, but not functional knowledge, would be critical for tool categorization. The reason for this is that contextual relationships are much more frequent in our culture than functional relationships. For example, in the house, tools are generally placed together based on their context of use rather than based on their function (e.g., toothbrush in the bathroom, not with shoe brush). Likewise, when they make coffee, people need to seek and group tools that are to be used together, rather than tools that share the same function.

To test this hypothesis, we created an ambiguous, open-ended tool categorization task similar to a S-ADL task, in which the same tools could be categorized either on a functional criterion, or on a contextual criterion. Age-related preferences have been suggested, with older adults tending to favor thematic over taxonomic relationships (see Estes et al., 2011), yet little is known about the preferred criterion of healthy controls in tool categorization tasks comparing functional versus contextual associations. Likewise, there is no data in this regard on patients with dementia.

On this ground, the aims of this study were twofold. First, to test healthy controls' preferred categorization criterion in a tool categorization task. If functional knowledge is critical to perform activities of daily living, then healthy controls should match tools based on their function (e.g., to draw, to stick). If contextual knowledge is critical, then they should match the tools based on their context of use (e.g., kitchen, garage). Second, our goal was also to test the performance of patients with dementia. If contextual knowledge is critical for tool knowledge, then patients should demonstrate a deficit of contextual, rather than functional knowledge. Patients with either Alzheimer's disease (AD) or semantic dementia (SD) were selected because they typically have semantic memory impairments (Bozeat et al., 2000; Hodges, 2000), apraxia of tool use (Lesourd et al., 2013), as well as S-ADL impairments (Giovannetti et al., 2002, 2006; Jarry et al., 2021).

Materials and Methods

Participants

Twenty healthy controls and thirty patients with dementia were recruited for the study (Table 1). The patients were recruited over a two-year period from two French outpatient memory clinics (Angers, Rennes), in the context of a larger research project on apraxia and dementia. They were included if they had been

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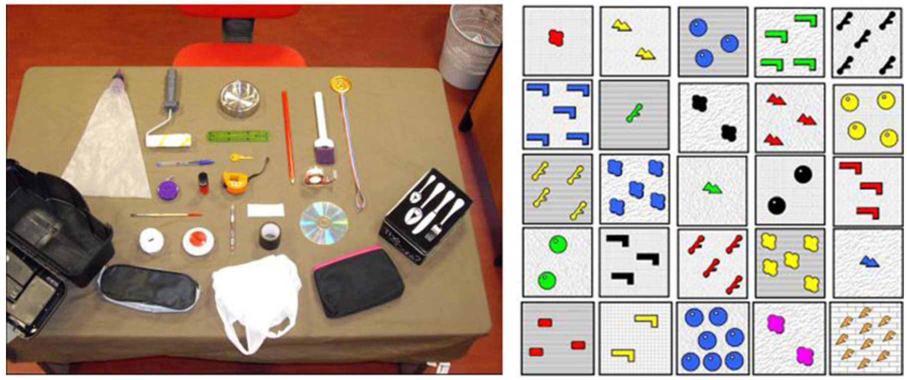

Figure 1. Materials used in the tool categorization (left panel) and picture categorization (right panel) tasks.

diagnosed with Alzheimer's disease (AD; McKhann et al., 2011) or semantic dementia (SD, or semantic variant of primary progressive aphasia; Gorno-Tempini et al., 2011; Neary et al., 1998) based on neurological examination, neuropsychological assessment, imaging data, and biomarker analysis. Participants were not included if the diagnosis was uncertain (for patients); if they had history of neurological condition or long-standing psychiatric illness; if their cognitive or mood state was incompatible with testing (e.g., low attention/arousal, depression); if they had medical treatments incompatible with the protocol; if they had a rheumatologic condition incompatible with action tests (e.g., severe arthritis); if they had a MMSE score below 10. Twenty patients with Alzheimer's disease, and ten patients with semantic dementia, met the inclusion criteria. There was 100% sample overlap with previous studies (Baumard et al., 2016, 2019). The study was conducted in accordance with the Declaration of Helsinki and approved by local ethic committee (Western Protection to Persons Committee II, n° 2012/32).

Neuropsychological assessment

All participants were administered the MMSE (Folstein et al., 1975) and the BEC questionnaire (Battery of Cognitive Efficiency; Signoret et al., 1989; see also Baumard et al., 2016) as a measure of global cognitive functioning. The latter contains a series of subtests assessing various neuropsychological domains, among which episodic memory (i.e., three immediate free recall of eight words; delayed free and cued recall of six pictures) and semantic memory (i.e., category fluency, picture naming). Patients with dementia showed impairments on a pantomime of tool use test (Baumard et al., 2019) as well as in simulated activities of daily living (for full details on the task, see Jarry et al., 2021). Semantic tool knowledge was tested with the same functional and contextual matching tasks used in the study by Baumard et al. (2019). In the functional matching task, the participants had to select among an array of four pictures the one that had the same function as the target tool (e.g., target = match; choice = *lighter*, pen, coffee maker, colander). In the contextual matching task, the participants had to select one of four possible contexts of use (e.g., target = match; choice = *anniversary*, wedding, Christmas day, baptism). The criteria were not given to the participants explicitly. There were two example, corrected items, for each condition, then ten items in each condition (functional, contextual). Each correct answer given within 20 seconds was worth 1 point (maximum score = 10 per condition).

As shown in Table 1, patients showed impairments in all the clinical tasks. In more detail, SD patients showed impairment in all but the visual episodic memory and functional association tests. AD patients failed all but the functional association test.

Tool categorization

Materials

The stimuli consisted of 25 everyday tools (Fig. 1). They could be matched together based on either a functional criterion (e.g., both a pen and mascara share the same "trace" function) or a contextual criterion, namely, the room where they are usually stored in one's house (e.g., a pastry brush and a timer are generally used in the kitchen; Table 2). This means that the participants had to make a choice between the two categorization criteria. The latter were defined and fixed a priori by the authors. The study focused on these criteria because they are central in cognitive models of apraxia and tool use (Osiurak, 2014; Roy & Square, 1985; Stamenova et al., 2012). Three principles guided the design of the task. First, categorization had to be based on visual rather than verbal information. Second, we also wanted participants to manipulate actual tools rather than pictures, partly to enhance the ecological value of the task, and partly because cognitive performance is better with real-world objects than with photographs of objects (Snow et al., 2014). Third, while semantic tool knowledge is generally assessed with structured picture categorization tests (i.e., one matching criterion, limited number of foils, different tools for different matching criteria), we created an open-ended task and selected a large set of tools that could be matched on at least two different criteria – allowing to detect individuals' preferred criterion.

There were five "unclassifiable" tools (i.e., plastic bag, medal, ashtray, key, CD-ROM) that corresponded neither to a contextual nor to a functional criterion. They were added to simulate everyday tool categorization. For example, tidying one's house implies to navigate among dozens of manufactured objects, as well as to make both simple matches (e.g., the toothbrush always goes in the bathroom) and more arbitrary choices based on individual habits (e.g., where should one store the ashtray?).

Instructions and procedure

The examiner displayed the 25 tools following a fixed layout (Fig. 1), and gave the following instructions: *"I will now ask you to arrange the tools in an organized manner, by putting together the tools that go/match together."* These instructions were chosen to be

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Table 2. Contextual and functional matching criteria for the tool categorization task

	Contextual criterion					Functional criterion				
	Office	Kitchen	Workshop/ garage	Bathroom	Nonclassifiable	To contain	To write or trace	To bind or fix	To spread or overlay	To mea-sure
Pencil case	X					X				
Pen	X						X			
Tape	X							X		
Paintbrush	X								X	
Ruler	X									X
Kitchen box		X				X				
Pastry bag		X					X			
Twine		X						X		
Pastry brush		X							X	
Timer		X								X
Toolbox			X			X				
Bricklayer's pencil			X				X			
Duct tape			X					X		
Paint roller			X						X	
Semirigid tape measure			X							X
Toilet bag				X		X				
Mascara				X			X			
Bandage				X				X		
Nail polish				X					X	
Tape measure (seamstress)				X						X
Plastic bag					X	X				
Medal					X					
Ashtray					X					
Key					X					
CD-ROM					X					

as neutral as possible, in that they did not mention explicitly the categorization criteria. The examiner insisted to the participant that she/he should consider all of the tools without forgetting any. The examiner was allowed to encourage participants but not to give any clue as to how to perform the task. There was no time limit so the task ended when the participant said she/he had finished. From this point, the examiner started a verification procedure designed to avoid ambiguous responses and to reduce the influence of attentional factors. Starting from the participant's left, the examiner pointed at each group of tools one after the other, saying *"Do these tools belong together or not?"* If the participant answered "yes," and for any isolated tool, the examiner pointed at each of the surrounding tools and asked *"Is this tool alone, or do you want to match it with another of these tools?"* During this phase, participants could move tools to change their initial response, and only the final arrangement was coded.

Coding system

The performance was videotaped and later coded according to the following criteria:

(1) Total number of associations (i.e., the total number of pairs of tools/objects). For example, a group including the pen, the ashtray, and the toolbox resulted in 3 associations: Pen/ashtray, pen/toolbox, and ashtray/toolbox. There were 300 possible associations;

(2) Percentage of functional associations (i.e., the number of functional associations out of the total number of associations performed by the participant), hereafter called the $TC^{function}$ score. There were 34 possible functional associations, meaning that if a participant made only one group with all of the 25 objects, she/he would make 11.3% of functional associations;

(3) Percentage of contextual associations (i.e., the number of contextual associations out of the total number of associations performed by the participant), hereafter called the $TC^{context}$ score. There were 50 possible contextual associations, so if a participant grouped all the tools, she/he would make 16.7% of contextual associations. Pretests indicated that some participants tended to put the "nonclassifiable" tools together, which they frequently justified by the fact that these objects do not go in specific rooms of the house. If a participant associated two or more "nonclassifiable" tools together, these associations were therefore considered to be contextual rather than functional or "other";

(4) Percentage of other associations (i.e., the number of associations that did not correspond to predetermined criteria, out of the total number of associations performed by the participant). There were 216 possible "other" associations, so grouping all the objects would result in 72.0% of "other" associations.

As an example of the coding system, if a participant grouped the pen, tape, and twine, we coded one contextual association (pen/tape), one functional association (tape/twine), and one other association (pen/twine).

Picture categorization

In order to control for visual categorization skills, participants were presented with 25 meaningless pictures printed on square paper cards (Fig. 1). Pictures and categorization criteria were inspired by the classical Wisconsin Card Sorting Test (Grant & Berg, 1948). The instructions, procedure, and coding system were similar to those from the tool categorization task. The participants could match the pictures according to color, shape, number of figures, background, or "other" criteria. In some instances, two pictures could be simultaneously matched on two different criteria (e.g., two black circles and two green circles together are matched on both shape and number of figures). In these cases, the examiner asked the participant to justify her/his response. As for the tool

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Table 3. Performance in the tool and picture categorization tasks

	Healthy controls	Patients with dementia	U	*p*	d*
Tool categorization task					
Total possible associations	300	300	–	–	–
Total observed associations	51.0 (15.1)	90.7 (62.3)	191.5	.22	–
% Associations function	8.7 (6.3)	21.9 (21.9)	99.5	< .001	−0.67 (large)
% Associations context	53.8 (11.8)	20.7 (11.7)	576	< .001	0.92 (large)
% Associations other	37.5 (7.7)	57.4 (19.1)	91	< .001	−0.70 (large)
Picture categorization task					
Total possible associations	300	300	288	–	–
Total observed associations	56.7 (4.4)	56.8 (12.7)	268.5	1.	–
% Associations color	13.8 (18.9)	18.2 (18.5)	316.5	1.	–
% Associations shape	26.9 (19.0)	19.5 (18.0)	260.5	1.	–
% Associations number	7.2 (6.0)	8.6 (8.9)	358.5	1.	–
% Associations background	6.8 (1.8)	6.3 (2.5)	206.5	.80	–
% Associations other	1.9 (2.3)	4.1 (4.9)	288	.51	–

Values are mean values. Values between brackets are standard deviations.
*Cliff's delta for effect size, reported for significant differences only.

categorization task, the layout was fixed and there were 300 possible associations.

Statistics

Nonparametric statistics were preferred because most variables were not normally distributed (as verified with Shapiro-Wilks tests). Mann-Whitney tests and Wilcoxon tests were used to test between-group and within-group differences, respectively. Effect sizes were estimated using Cliff's delta. Individual impairments were detected using the minimum and maximum scores of the HC group as cut-off scores. P-values were adjusted with Holm's method. A "tendency toward significance" was reported when *p*-value was no longer significant after application of Holm's correction. All the analyses were performed using R statistical software.

Results

Tool categorization in healthy controls

As shown in Table 3 and Table 4, healthy individuals made more contextual than functional associations (W = 210.0, $p < .001$, $d = 0.99$, large). In fact, 100% of them made more contextual than functional associations. If a participant made only one group containing all of the objects, one should observe 16.67% of contextual associations, 11.33% of functional associations, and 72.00% of other associations ("Probable values"). The comparison between probable and observed values showed that healthy controls made more contextual associations ($U = 400.0$, $p < .001$, $d = 1$, large), less functional associations ($U = 100.0$, $p = .004$, $d = -0.5$, large) and less other associations ($U = 0.0$, $p < .001$, $d = -1$, large) than chance. To sum up, healthy individuals prioritized the contextual criterion over the functional criterion.

Tool categorization in patients with dementia

In order to better qualify the performance of patients, we counted the number of isolated tools (i.e., tools that were not associated with other tools), the number of groups of tools (i.e., association of two or more tools), and the number of tools in each group. The number of isolated tools was virtually the same in both groups (mean in patients = 3.2, standard deviation = 4.1; mean in controls = 2.3, sd = 2.8; $U = 275.5$, $p = .62$). It means that the patients did try to arrange the tools. However, patients made fewer groups of tools than controls (mean number of groups in patients = 3.7, standard deviation = 1.8; mean in controls = 4.7, sd = 0.9; $U = 450.5$, $p = .008$, $d = 0.5$, large), with more tools in each group (mean number of tools per group in patients = 7.7, sd = 4.8; mean number in controls = 4.9, sd = 0.8; $U = 187.5$,

Table 4. Individual tool categorization scores

Patient	$TC^{function}$	$TC^{context}$
HC group (mean (SD))	8.7 (6.3)	53.8 (11.8)
Max	25.9	67.9
Q3	11.0	63.8
Q2	7.8	54.5
Q1	5.5	45.6
Min	0.0	24.2
Patients w/ dementia	21.9 (21.9)	20.7 (11.7)
Alzheimer's disease	**25.7 (25.6)**	**20.3 (0.1)**
AD.01	10.2	25.4
AD.02	**25.9**	**18.5**
AD.03	11.7	**18.0**
AD.04	14.8	**18.3**
AD.05	13.5	**15.9**
AD.06	**100.0**	**0.0**
AD.07	12.2	**17.6**
AD.08	5.9	67.6
AD.09	11.5	**23.1**
AD.10	17.1	**23.7**
AD.11	12.2	**15.5**
AD.12	13.2	**22.4**
AD.13	11.6	**19.8**
AD.14	9.4	**18.1**
AD.15	10.7	**16.7**
AD.16	**34.6**	**19.2**
AD.17	22.6	29.0
AD.18	**37.9**	**10.3**
AD.19	**58.3**	**16.7**
AD.20	**81.0**	**9.5**
Semantic dementia	**14.3 (8.1)**	**21.6 (9.7)**
SD.01	9.9	**17.0**
SD.02	11.6	**20.7**
SD.03	10.5	42.1
SD.04	**36.4**	**9.1**
SD.05	**14.7**	**16.0**
SD.06	10.0	35.0
SD.07	14.0	**18.0**
SD.08	16.4	**20.5**
SD.09	9.7	**17.2**
SD.10	9.5	**21.0**

TC = tool categorization, AD = Alzheimer's disease, SD = semantic dementia.
Bold values correspond to significant differences to controls. Individual pathological scores correspond to scores below the minimum or above the maximum score observed in healthy controls.

$p = .052$, tendency). Patients with dementia thus showed abnormal tool categorization skills.

As shown in Table 3 and Table 4, they made less contextual associations, but more functional and other associations than healthy controls. The comparison between probable and observed values showed that patients made more functional associations ($U = 630.0$, $p = .004$, $d = 0.4$, medium) than chance, contrary to healthy controls (see section 3.2).

In more detail, patients with Alzheimer's disease made less contextual associations ($U = 313.0$, $p = .002$, $d = 0.56$, large), but more functional associations than healthy controls ($U = 32.0$, $p < .001$, d = -0.84, large; see Table 4). Patients with semantic dementia formed less contextual associations than healthy controls but the difference did not reach significance ($U = 135.0$, $p = .128$). They also formed more functional associations than healthy controls ($U = 19.5$, $p < .001$, d = -0.80, large). The difference between patient groups was not significant (both ps > .23). Finally, there was no correlation between the MMSE score and BEC score on the one hand, and the percentage of functional or contextual associations on the other hand (all $ps > .80$).

Picture categorization

Contrary to what was observed for the tool categorization task, patient showed normal performance in the picture categorization task.

Discussion

The first goal of this study was to test healthy control's preferred categorization criterion in the tool categorization task. We found that healthy individuals clearly prioritized the contextual criterion, over the functional criterion. The second goal of this study was to compare the performance of healthy individuals and patients with dementia. The results showed that patients made less contextual associations, but more functional associations than healthy controls. We discuss each of these findings in the next sections.

Semantic cognition in healthy individuals

S-ADL tasks are composite tests that put loads on various cognitive factors, like executive functioning or episodic memory (Giovannetti et al., 2008, 2021; Roll et al., 2017). Classical models of apraxia are structured around functional knowledge, which may be critical to retrieve the prototypical function of tools (e.g., a brush allows a "tracing" action; Roy & Square, 1985; Stamenova et al., 2012). Models of tool use like the Four Constraints Theory (4CT; Osiurak, 2014) have rather insisted on the role of contextual knowledge. The 4CT assumes that tool use depends (among other processes like executive functioning, working memory, and motor simulation) on semantic reasoning, which is the ability to navigate mentally in the social space to seek tools having the right properties for the task. So, functional knowledge contains information about the action performed with the tool, whereas contextual knowledge contains spatial information about how the society is organized (e.g., one may find different types of brushes on specific shelves of the supermarket). The finding that healthy individuals prioritized the contextual criterion over the functional criterion in the tool categorization task is, therefore, better predicted by the 4CT. In an ambiguous situation where participants may categorize tools based on either function or context (or other criteria), contextual knowledge seems to be more salient than functional knowledge or other criteria. In all likelihood, the view of several tools triggers knowledge about their context of use (the "where"), before activating knowledge about what these tools are made for (the "what for"). It does not mean that functional knowledge is not necessary to use tools. Contextual knowledge is probably more salient than functional knowledge because it is more frequently used to categorize tools in our culture, and because it may be important in the first phase of S-ADL (to group objects that are used in the same space/event). In contrast, functional knowledge might be necessary in the second phase of S-ADL, to use the tools in the proper manner.

The contextual advantage is true, at least, when individuals are instructed to categorize the tools with no other indication; in a goal-directed task, the goal would probably drive other tool-tool associations, an assumption that future studies may test. Furthermore, we cannot rule out the possibility that the instructions led healthy controls to prioritize a contextual criterion. Future studies may thus compare the effects of different instructions.

Semantic cognition in patients with dementia

In our findings, patients made less contextual, but more functional associations than healthy controls. The normal performance in the picture categorization task suggests that the tool categorization deficit was caused by specific alterations of semantic tool knowledge rather than general visual categorization or attentional impairments. Likewise, the absence of correlation between cognitive measures and categorization scores suggests that the tool categorization deficit was not caused by general cognitive impairment. Semantic cognition depends on a distributed network encompassing the anterior and posterior middle temporal lobes, as well as frontal and parietal brain regions (Jefferies et al., 2020; Kalénine et al., 2009; Lambon Ralph et al., 2017; Schwartz et al., 2011). These are typical lesion sites of semantic dementia and Alzheimer's disease, which may explain our findings.

That said, why did patients make more functional associations than healthy controls? A first, possible explanation is that patients formed more functional associations than controls, just because they formed less contextual associations: Since healthy controls prioritized contextual associations, and since patients formed less contextual associations than healthy controls, they had mechanically a higher chance than controls to categorize tools based on function. Nevertheless, this hypothesis is unlikely, because, by categorizing tools randomly, patients had more chance to form "other" associations (72%) than functional associations (12%). The observed functional/contextual dissociation may instead suggest that functional and contextual knowledge are distributed across different neuroanatomical and functional semantic systems (see Merck et al., 2019 for a similar interpretation). It is also plausible that functional knowledge itself is actually distributed across different brain regions. According to the hub-and-spoke theory of semantic cognition (Patterson et al., 2007), high-level semantic information arises from different sources of information. In this view, matching tools on their function may rely not only on semantic but also on nonsemantic factors. As mentioned above, functional knowledge is related to action. A growing body of evidence has indicated that semantic and motor cognition are intermingled (for a review, see Pulvermüller et al., 2014), and positive correlations have in fact been demonstrated between functional matching tasks, and mechanical problem-solving tasks that do not require prior tool knowledge (Jarry et al., 2013). Furthermore, functional knowledge is sometimes included in

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thematic categories, and thematic knowledge has been associated with the left posterior cortex, which is involved in action processing (e.g., Kalénine & Buxbaum, 2016). The high frequency of functional associations in our study may, therefore, be interpreted as a compensation of impaired contextual knowledge by nonsemantic factors (e.g., perception, action knowledge, motor simulation, reasoning). Beyond action, it is also plausible that patients with dementia actually made visual rather than functional associations. Indeed, objects manufactured to serve similar functions also share similar perceptual features (e.g., pencil/mascara/paintbrush) so that functional and perceptual criteria are frequently superimposed. This explanation is in line with the normal performance of patients in the picture categorization task, where visual, but not tool-related semantic information drives the performance. So, it may be assumed that patients compensated contextual knowledge deficits (presumably following temporal lobe or temporo-parietal lesions) by taxonomic knowledge calling for visual areas (Kalénine et al., 2009) typically spared in these diseases (but see also Schwartz et al., 2011, on a possible role of the temporal lobe in the retrieval of taxonomic knowledge in verbal modality). This dissociation may explain why patients with Alzheimer's disease are sensitive to functional/perceptual distractors (e.g., salt/sugar; Giovannetti et al., 2010). In our findings, patients with Alzheimer's disease seemed to form more functional associations than patients with semantic dementia (26 and 14%, respectively), a difference that future studies may investigate.

From semantic to social knowledge

If functional knowledge is related to visual and action properties of tools, then what could be the specific properties of contextual knowledge? Indeed, two tools that can be found in the same "context" (an umbrella term) have good chances to be linked by spatial (e.g., the coffee machine and microwave are close to one another), event (e.g., both are frequently used in the same "dining" event), or production relationships (e.g., both are manufactured, technological products; Estes et al., 2011). It is proposed that the common denominator behind most of thematic subcategories consists of social norms. In social psychology, social norms correspond to what most people would approve or disapprove (injunctive norms), and to what most people do (descriptive norms; Cialdini et al., 1990). Social norms guide behaviors in ambiguous situations, render the actions of others predictable, and protect ideas valued in a given cultural context (Brauer & Chaurand, 2009). Back to tool categorization, the reason why tools can be found in the same space or used in common events is that social norms condition where they *should* be stored and used. For example, no one would store her/his fridge in the dining room even though it may be convenient in some instances. In our modern societies, contextual knowledge is largely favored over functional knowledge. For example, supermarkets and e-commerce sites, as well as our homes, are clearly organized along contextual rather than functional relationships (e.g., products are generally grouped into "kitchen," "garden," and "bathroom" categories rather than "screwing," "sawing," "sticking" categories). In this view, contextual categorization consists in replicating social norms, hence the preference of healthy controls for this criterion. This approach amounts to considering that what is lost in patients with dementia is neither the ability to categorize (seeing their performance in the picture categorization task) nor perceptual/functional knowledge (seeing that functional matching was higher in patients than in healthy controls), but rather the ability to reproduce "social structures," that is, the habit or knowledge of – or the ability to seamlessly navigate in – categories that are socially relevant at a given historical moment. As a matter of fact, self-centeredness and egocentric world view have been described in semantic dementia (Duval et al., 2012), with some patients developing "bad manners" (e.g., cleaning the table while hosts are still eating), that is, behaviors that do not fit social norms. Future studies may test the relationships between functional and contextual knowledge on the one hand, and nonsemantic factors (e.g., spatial representations) on the other hand.

Conclusion

Using an original, open-ended, and ambiguous tool categorization task, we have shown that healthy controls prioritized a contextual, over a functional criterion. Patients with dementia had mainly contextual knowledge deficits, while they prioritized a functional/visual categorization criterion. This has led us to fractionate tool knowledge and to argue that functional knowledge may be a complex, superordinate category distributed across both semantic and nonsemantic/taxonomic neural networks. With a similar approach, we have argued that contextual knowledge may actually be the name of higher-order social knowledge applied to tool knowledge. The dissociations we report here support a dissociation between visual categorization ("what") and functional knowledge ("what for") on the one hand, and contextual knowledge ("where") on the other hand.

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