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ABSTRACT

In addition to its use in communication, language appears to have a variety of extra-communicative functions; disrupting language disrupts performance in seemingly non-linguistic tasks. Previous work has specifically linked linguistic impairments to categorization impairments. Here, we systematically tested this link by comparing categorization performance in a group of 12 participants with aphasia and 12 age- and education-matched control participants. Participants were asked to choose all of the objects that fit a specified criterion from sets of 20 pictured objects. The criterion was either “high-dimensional” (i.e., the objects shared many features, such as “farm animals”) or “low-dimensional” (i.e., the objects shared one or a few features, such as “things that are green”). Participants with aphasia were selectively impaired on low-dimensional categorization. This selective impairment was correlated with the severity of their naming impairment and not with the overall severity of their aphasia, semantic impairment, lesion size, or lesion location. These results indicate that linguistic impairment impacts categorization specifically when that categorization requires focusing attention and isolating individual features – a task that requires a larger degree of cognitive control than high-dimensional categorization. The results offer some support for the hypothesis that language supports cognitive functioning, particularly the ability to select task-relevant stimulus features.

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1. Introduction

To what degree does human cognition depend on language? Contrary to the view that language simply makes use of already existing concepts and cognitive faculties (Fodor, 1975; Li and Gleitman, 2002), there is mounting evidence that language is “potentially catalytic and transformative of cognition” (Bowerman and Choi, 2001). Indeed, not only does language appear to be instrumental in the learning of concepts during development (e.g., Balaban and Waxman, 1997; Casasola, 2005; Yoshida and Smith, 2005), but as initially hypothesized by

William James (1890) categorization may continue to depend on language in adulthood (Lupyan et al., 2007; Lupyan, 2009).

If language affects cognition, then language deficits may produce cognitive deficits. This idea was discussed at length by the German neurologist Kurt Goldstein in the context of possible cognitive impairments concomitant with aphasia (1924, 1948). Rejecting the view prevalent at the time that aphasia was a disorder of general intelligence (Jackson, 1878), Goldstein argued that a loss of words did not bring with it a loss of thoughts, but an impairment of naming was also not circumscribed to language:

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Thinking is not only expressed in language, but language influences in turn thought formation... Language is not only a means to communicate thinking; it is also a means to support it, to fixate it. Defect in language may thus damage thinking (Goldstein, 1948).

Indeed, following Goldstein's initial observations (see Noppeney and Wallesch, 2000 for review), a number of researchers found that linguistic impairments were often correlated with difficulties in nonverbal sorting and categorization tasks. For example, individuals with aphasia were found to have trouble sorting objects by color—a task requiring selectively focusing on a specific dimension while overlooking differences in other dimensions such as shape (De Renzi and Spinnler, 1967). Cohen et al. likewise noted a specific impairment in encoding object features stressed by the experimenter (Cohen et al., 1981; see also Wayland and Taplin's, 1982 discussion of patients with aphasia failing to organize feature set information, and Vignolo, 1999 for review).

In an effort to systematize the observed patterns of results, the so-called Konstanz group concluded that "... aphasics have a defect in the analytical isolation of single features of concepts" (Cohen et al., 1980, 1981), yet are equal to controls "when judgment can be based on global comparison" (Cohen et al., 1980). In their examination of the anomic patient LEW, Davidoff and Roberson reached a similar conclusion, arguing that when a grouping task requires attention to one category while abstracting over others, LEW is "without names to assist the categorical solution. Where patients such as LEW can name, they can categorize." (Davidoff and Roberson, 2004).

In a study especially relevant to the present work, Semenza et al. (1992) measured the ability of a varied group of patients with aphasia to select the stronger of two associates given a target item. The patients were asked to choose the better of two alternatives related to the target (e.g., ring) in a taxonomic relationship (necklace vs belt) and in a thematic relationship (finger vs wedding). Although the patient group performed worse than the control group on both trial types, greater impairments in confrontation naming predicted poorer performance specifically for the taxonomic trials.

Although these studies suggest an association between linguistic and categorization impairments, no consensus could be reached, owing to wide variety of methods of diagnosing and testing the patients (cf. Caramazza et al., 1982; De Renzi and Spinnler, 1967; Hjelmquist, 1989; Semenza et al., 1992; Wayland and Taplin, 1982; see Vignolo, 1999 for discussion). For example, it is unclear to what degree the deficits observed by Semenza et al. (1992) were due to failures of the categorization process versus disrupted semantic knowledge (cf. Caramazza et al., 1982) and it is unclear whether the studies of the patient LEW (Roberson et al., 1999; Davidoff and Roberson, 2004) generalize to a broader population.

Here, we report a systematic investigation of categorization deficits in aphasia by comparing performance of participants with aphasia to age- and education-matched control participants on a task that required selecting pictures of common objects that matched a particular criterion. For example, one criterion asked participants to click on all the

farm animals; another asked to choose all "things that are green" (see Appendix for a full listing).

One reason why naming impairments may lead to categorization impairments is that language is inherently categorical (i.e., words denote categories) and as such helps to dynamically cohere entities that are otherwise too distinct (Lupyan, 2012a). A label like "red" for example may facilitate forming a category of red things independently of their semantic categories. Indeed, in a series of studies investigating the impact of aphasia on detecting commonalities between objects, Koemeda-Lutz et al. found that patients with aphasia were impaired in detecting common properties of sequentially shown objects. The authors observed that "red cherries and red bricks may be judged to be alike mainly via what is concentrated and coined in the verbal label 'red'" (Koemeda-Lutz et al., 1987).

Our main prediction was that individuals with aphasia would be selectively impaired on trials that required categorizing according to a specific dimension, e.g., choosing all the green items while abstracting over shape, semantic class, etc. We call such trials *low-dimensional*. We reasoned that because such categories cohere on the basis of one or a small number of dimensions, they may require more on-line support from language. Language impairments, particularly naming impairments, may therefore lead to a failure in forming the task-relevant category representation resulting in a lower rate of correct target selection. In contrast, grouping together items that cohere on numerous dimensions such as a pillow and a blanket (*high-dimensional* trials) does not require the same level of selective representation/cognitive control and can be accomplished by relying on broader inter-item associations. Performance on these trials was predicted to be less affected by linguistic impairments such as naming.¹ So, although grouping together a cow, a pig, and a chicken as instances of farm animals depends on semantic knowledge of what animals are typically found on farms, forming this type of classification on our account does not require a high level of active selection or cognitive control and can be accomplished by activating a broad semantic representation of things-associated-with-farms (see Lupyan et al., 2012 for discussion). Note that our predictions concern the possible contributions of language in constructing task-relevant category representations on-line. So, although it is true that semantic impairments observed particularly in Wernicke-type aphasias manifest in disordered conceptual organization (Whitehouse et al., 1978; Caramazza et al., 1982), our present goal is to test the hypothesis that language may be implicated in constructing certain types of categories (low-dimensional) controlling for any concomitant semantic deficits.

¹ Our notion of category dimensionality is similar to Sloutsky's distinction between sparse categories—those cohering on only a small number of dimensions, and dense categories—those in which many of the dimensions covary (Sloutsky, 2010). It is also related to the distinction of rule-based versus information-integration categories (e.g., Ashby et al., 1999; Waldron and Ashby, 2001). These authors have argued that learning low-dimensional/sparse/rule-based categories appears to depend more on language than learning high-dimensional/dense/similarity-based categories.

2. Methods

2.1. Participants

We recruited 12 participants with left unilateral CVA lesions who had been acutely diagnosed with aphasia and 12 age- and education-matched controls from the Moss Neuro-Cognitive Rehabilitation Research Registry (Schwartz et al., 2005). Because we were primarily interested in the effect of naming impairments on categorization, we selected individuals with anomic aphasia.² The characteristics of this group are shown in Table 1. Naming impairments were assessed by using the Philadelphia Naming Test (Roach et al., 1996) in which patients see 175 pictures of common objects and are given 30 sec to name each one. General semantic impairments were assessed by using the American version of the Camels and Cactus test (Bozeat et al., 2000) in which patients see 64 pictures and for each, have to select among four pictorial choices, the one that is most strongly associated with the item, e.g., matching a picture of an orange to a glass of orange juice. Structural lesion images were acquired by MRI or CT. For MRI scans, lesions were segmented manually, registered to a common template (Montreal Neurological Institute space “Colin27” volume: Holmes et al., 1998), and inspected by an experienced neurologist. For CT images, an experienced neurologist drew lesion maps directly onto the Colin27 volume. For more details, see previous voxel-based lesion-symptom mapping studies using the same procedure (Schwartz et al., 2009; Walker et al., 2011).

2.2. Procedure

Participants were tested individually and told that they would be seeing groups of pictures along with a category or property description, and that their task was to choose all of the pictures that matched the description by clicking on them by using a mouse or for some patients a touchscreen. Each trial began with a prompt informing the participants of the category criterion they should use. Participants then clicked the mouse to reveal a four-row by five-column array of color pictures on a white background. The criterion, e.g., THINGS THAT ARE GREEN, was prominently displayed above the pictures throughout the trial. A sample trial is shown in Fig. 1. Participants could select as many or as few pictures as they deemed appropriate. Clicking on an object caused a gray frame to appear around it marking it as selected. Clicking it again un-selected the object allowing participants to change their mind. There was no time limit; the trial was terminated when the participant clicked a large “Done” button at the bottom of the screen. Subjects completed two blocks of 40 trials.

² One participant was diagnosed with conduction aphasia, but we included this participant because (s)he primarily exhibited a lexical impairment (extremely poor picture naming and word-to-picture matching) with other language functions such as auditory discrimination (83% correct) and sentence comprehension (83% correct) relatively spared.

2.3. Materials

The targets and distractors were drawn from 260 color drawings of common objects (Rossion and Pourtois, 2004). These stimuli were used to construct 34 separate categories, 17 low-dimensional categories and 17 high-dimensional categories. The *low-dimensional* categories identified targets that cohered on the basis of one or few dimensions. For example, the targets in a THINGS THAT ARE BLUE trial could vary in shape, size, and semantic category. The one thing they had in common was that they were all blue. The *high-dimensional* categories identified targets that cohered on multiple dimensions, that is, were related to each other in multiple ways. High-dimensional trials included both role-governed/ad-hoc categories such as NON-FOOD THINGS FOUND IN A KITCHEN, as well as “common” categories such as FRUIT. What distinguished both of these from *low-dimensional* categories was the absence of any single dimension on which targets could be distinguished from non-targets. See the Appendix for a full list of trials.

For each category we designated four pictures as targets (though participants were free to select however many targets they wished). For example the targets of the BODY PARTS category were *hand*, *leg*, *toe*, and *finger*. An item could serve as a target for only a single category, despite some items being sensible targets in more than one category. Items could appear as distractors on multiple trials.

Pictures serving as targets in the two trial types (*low-dimensional* vs *high-dimensional*) did not differ in naming reaction times (RTs), naming accuracy, name agreement, imageability, or familiarity, all $F_s < 1$ (see Rossion and Pourtois, 2004 for definitions of these measures). There was a reliable difference in visual complexity with targets in the *low-dimensional* trials having lower complexity than targets in the *high-dimensional* trials, $F(1,211) = 15.29$, $p < .0005$ [this effect was less reliable when we examined the average visual complexity of the target set for each category, $F(1,32) = 3.73$, $p = .062$]. Results of additional norming studies can be found in Lupyan et al. (2012).

3. Results

The main dependent variable was the proportion of targets chosen on each trial. Trial-type (*low-dimensional* vs *high-dimensional*) and group (aphasic vs control) were entered into an ANOVA as within- and between-subject factors, respectively. Participants with aphasia had only marginally lower target-selection rates compared to control participants, $F(1,22) = 3.23$, $p = .086$. Performance in both groups was poorer for the *low-dimensional* compared to the *high-dimensional* trials, $F(1,22) = 34.06$, $p < .0005$, and there was a reliable category-type by group interaction, $F(1,22) = 5.22$, $p = .032$. The two groups had equivalent performance on the *high-dimensional* type trials, $F < 1$, but participants with aphasia had a significantly lower rate of target-selection than controls on the *low-dimensional* type trials, $F(1,22) = 5.18$, $p = .03$ (Fig. 2). We also examined the time participants took to select the targets (including only the correct responses). Participants

Table 1 – Patient data.

Participant ID	Sex	Age	Education (yrs)	Aphasia subtype	WAB	PNT ^a	CCT	Low dim	High dim	Lesion volume (cm ³)	General location of lesion
65	F	71	12	Anomic	89.8	87	88	.738	.894	99.7	Fronto-temporal
206	M	56	16	Anomic	92.3	89	81	.820	.865	103.9	Fronto-temporal
904	F	63	12	Anomic	88.5	80	86	.796	.956	70.9	Fronto-parietal
419	M	41	12	Anomic	91.5	91	80	.838	.951	51.9	Fronto-temporal, Putamen
1088	M	46	18	Anomic	78.8	56	55	.913	.890	89.1	Temporal
1380	F	58	12	Conduction	55.6	7	70	.654	.863	50.5	Temporal, Caudate, Putamen
1392	M	65	19	Anomic	90.2	72	78	.823	.925	84.9	Fronto-temporal
1620	M	65	12	Anomic	92.9	78	77	.774	.888	5.4	Subcortical frontal
1764	F	39	15	Anomic	92.2	88	92	.890	.903	41.9	Fronto-temporal, Putamen
1780	M	60	14	Anomic	83.7	86	63	.758	.869	37.0	Fronto-temporal
4343	F	72	22	Anomic	88.1	95	88	.921	.950	41.0	Fronto-temporal
44	F	58	12	Anomic	95.2	97	89	.866	.964	78.5	Parietal-temporal

Note: WAB = Aphasia Quotient from the Western Aphasia Battery.

PNT = Philadelphia Naming Test. Control performance: $M = 97\%$, $SD = 1.8\%$ ($n = 20$, Schwartz et al., 2009).

CCT = Camels and Cactus Test of semantics. Control performance: $M = 89\%$, $SD = 11.4\%$ (Bozeat et al., 2000: British participants); $M = 89.8\%$, $SD = 5.6\%$ (Philadelphia participants $n = 20$; unpublished data collected at Moss Rehabilitation Research Institute).

Low Dim, High Dim = Percentage of targets selected.

a The numbers combine all error types. The overall naming rate is the best predictor of performance, as described in the text. Categorization performance was not selectively correlated with any specific type of naming errors.

with aphasia had significantly longer median per-click RTs ($M = 3029$ msec) than controls ($M = 1696$ msec), $F(1,22) = 15.28$, $p = .001$. More importantly, we found a significant category-type by group interaction, $F(1,22) = 4.90$, $p = .038$: participants with aphasia had longer RTs when categorizing the low-dimensional compared to high-dimensional trials, whereas control participants did not (Fig. 2).

We also analyzed selections of non-target items (false alarms – FA). The overall FA rate of participants with aphasia and control participants was very similar, $M_{FA} = 10\%$ of final selections, $F < 1$. FAs were significantly higher for low-dimensional than high-dimensional trials in both groups, $F(1,22) = 56.70$, $p < .0005$, with no reliable category-type by group interaction, $F(1,22) = 2.08$, $p = .16$.

Next, we examined which specific aspects of the aphasic profile (Table 1) were associated with categorization impairments. If the ability to select task-relevant dimensions is associated with linguistic impairments such as each individual's performance on the Philadelphia Naming Test, then it should predict performance on the low-dimensional trials, more than high-dimensional trials. We tested this prediction using a linear mixed effects model that included subjects and each category (e.g., green things) as random factors, thus combining subject- and item-based analyses (Baayen et al., 2008). Lower naming performance reliably predicted lower overall performance, $t = 2.56$, $\chi^2(1) = 5.97$, $p = .015^3$. Importantly, the effect of naming interacted significantly with trial-type (low- vs high-dimensional), $t = 2.43$, $\chi^2(1) = 5.94$, $p = .015$.

³ The t-value refers to the test of whether the best-fit coefficient from the linear mixed model differs from 0. The χ^2 term tests whether a model with the variable of interest, in this case, naming, provides a better fit to the data than a model without the variable, as revealed by a significantly greater log-likelihood ratio of the more complex model. All models also included years of education completed by the patient, which further improved the model fit.

Analyzing the low- and high-dimensional trials separately revealed that naming reliably predicted performance on the low-dimensional trials, $t = 2.75$, $\chi^2(1) = 6.45$, $p = .011$, but not high-dimensional trial, $t = 1.59$, $\chi^2(1) = 2.60$, $p = .11$. Semantics, assessed by the Camels and Cactus test predicted overall performance only marginally, $t = 1.645$, $\chi^2(1) = 2.77$, $p = .09$. Examining the low- and high-dimensional trials separately revealed that semantic impairments were associated with lower performance on the high-dimensional trials, $t = 1.97$, $\chi^2(1) = 3.86$, $p = .049$, but not low-dimensional trials, $t = 1.19$, $\chi^2(1) = 1.50$, $p = .22$, though the trial-type by semantics interaction was not significant. Controlling for naming, semantics no longer predicted target-selection performance.⁴ FA rates were not predicted by naming, $t < 1$, and were only marginally predicted by semantic impairments, $t = 1.64$, $\chi^2(1) = 2.78$, $p = .096$. Controlling for naming performance however, semantics became a highly reliable predictor of FAs, $t = 2.54$, $\chi^2(1) = 6.38$, $p = .012$ indicating that general semantic impairments led to a greater likelihood of selecting non-targets.

Finally, we examined whether the association between naming and categorization impairments depended on the general location of the lesion. As we discuss below, finding that naming impairments continue to predict categorization impairments independently of lesion location is consistent with the possibility that the categorization impairment stems from the functional naming impairment. Indeed, naming continued to predict categorization performance (proportion of targets selected) at the .01 level when controlling for overall

⁴ There remains a possibility that the failure to find a relationship between naming and categorization on high-dimensional trials arises from the greater variance in the performance on low-dimensional trials. When the variances were made comparable using an arcsine transformation, the interaction between category-type and naming remained reliable.

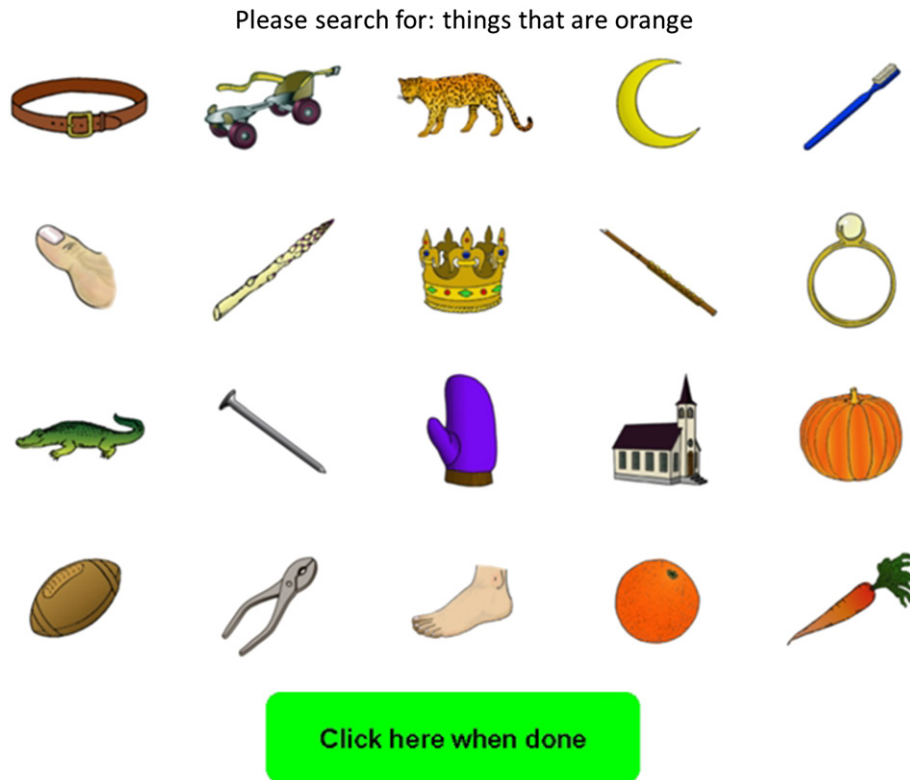


Fig. 1 – A sample low-dimensional categorization trial.

lesion size, and did not interact with the lesion site in any way. For example, naming predicted categorization performance regardless of whether the lesion extended into the left prefrontal cortex, $t = 2.62$, $\chi^2(2) = 7.21$, $p = .027$. Naming also remained a reliable predictor of categorization when we controlled for overall aphasia severity using the Western Aphasia Battery quotient.

4. General discussion

If language contributes to the human ability to represent items in terms of conceptual classes, naming impairments may lead to categorization impairments. Indeed, individuals with aphasia performed more poorly than matched control participants on a categorization task, showing poorer performance specifically on trials requiring grouping of objects that share only one or a few dimensions. The degree of categorization impairment was predicted by a behavioral linguistic predictor—naming performance—but independent of the location of the lesion that presumably caused the naming impairment. General semantic impairments predicted the likelihood of choosing non-targets and predicted lower target-selection rates on high-dimensional trials, consistent with the hypothesis that this latter type of categorization is more sensitive to semantic (i.e., real-world knowledge) deficits (cf. Semenza et al., 1992).

This result is consistent with the hypothesis that language reifies categories. Categories that have strong associations between their members (what we call here *high-dimensional*

categories) may cohere independently of language. Because dissolution of real-world knowledge (measured by the Camels and Cactus test) disrupts these associations, semantic impairments tend to track impairments in high-dimensional categorization. In contrast, categories held together by one or a small number of dimensions, may require more on-line support from language. For example, the ability to selectively attend to objects having a particular color—classifying objects into a category of RED THINGS—may be facilitated by naming insofar as words such as “red” help to group together objects that do not have pre-existing semantic associations and which differ substantially in surface appearance (e.g., a cherry and a brick) (e.g., Lupyan, 2008).

We have shown an association between naming and categorization, particularly for categorization trials that require greater selection of specific task-relevant dimensions. Such trials arguably place greater demands on cognitive control (e.g., Snyder et al., 2007; Novick et al., 2010), requiring subjects to group together items that only cohere on one or a few properties (e.g., a cherry and a brick have nothing in common except their color). An alternative to the claim that low-dimensional categorization is affected by naming impairments *per se* is that both the categorization and the naming impairments are caused by damage to cognitive control mechanisms. Indeed, the left-inferior frontal gyrus (LIFG, a region comprising Broca’s Area), is known to be involved in tasks requiring cognitive control (e.g., Thompson-Schill et al., 1997; Kan and Thompson-Schill, 2004) and deficits in cognitive control can lead to naming impairments (Jefferies

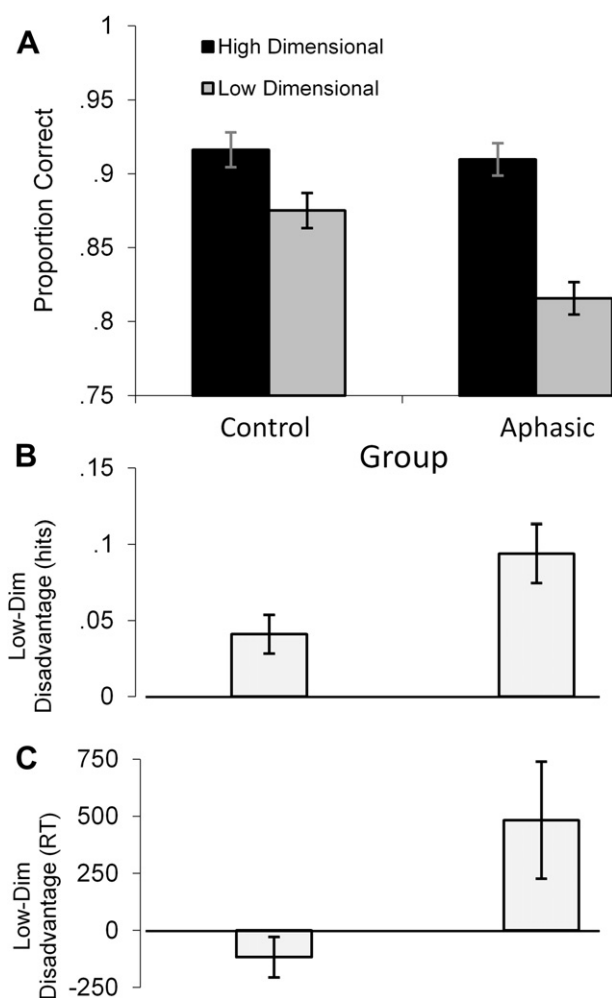


Fig. 2 – (A) Target-selection performance (hit rates) for the two participant groups. (B) The difference in hit rates between the low-dimensional and high-dimensional trials. (C) The difference in mean RTs of correct selections for the low-dimensional and high-dimensional trials. Error bars show ± 1 SE of the mean difference between the high- and low-dimensional trials.

et al., 2008). Insofar as naming itself is an act of categorization (to name is to categorize), it is not surprising that categorization deficits stemming from a failure of cognitive control can lead to naming impairments. However, in our sample, naming performance predicted categorization performance entirely irrespective of lesion site, e.g., the association between naming and categorization was observed for patients who had no lesions of the LIFG. The observation that naming predicted performance on the low-dimensional categorization trials controlling for lesion site and overall aphasic severity, suggests a bidirectional causal link between naming and categorization, perhaps modulated by cognitive control.

A causal link between language and categorization is also supported by studies that have investigated cognitive functions of language by attempting to experimentally up- or down-regulate language and observe the effect of this manipulation on cognitive performance. For example, down-regulating language by using verbal interference tasks

impairs performance on tasks requiring high levels of cognitive control such as task switching (Dunbar and Sussman, 1995; Baddeley et al., 2001; Emerson and Miyake, 2003; Miyake et al., 2004; Cragg and Nation, 2010). For example, Emerson and Miyake (2003) showed an increase in switching costs between simple tasks (single digit addition and subtraction problems) when participants repeated “the the the...” during the task as though this prevented them from using (covert) language to help guide them from one task to the next. More relevant to the present work, Lupyan (2009) showed that a verbal rehearsal task selectively impaired subjects’ ability to focus on specific perceptual dimensions such as size or color, leading to a performance profile similar to that shown by the pure anomic patient LEW on an almost identical categorization task (Experiment 7, Davidoff and Roberson, 2004).⁵

The idea that verbal category labels enhance categorical representations is also supported by studies exploring the effects of language on visual processing. For example, the ability to visually attend to all the objects in a given category, such as chairs, is enhanced immediately after hearing the basic-level term (i.e., the word “chair”) compared to knowing exactly what to attend, but not hearing the word (Lupyan and Spivey, 2010). Similarly, Lupyan and Swingley (2012) showed that an “up-regulation” of language achieved by having participants talk to themselves during a visual search task (e.g., to actually say the word “chair”) facilitated performance compared to just reading the word (see Lupyan, 2012b, for discussion).

In sum, our results show that acquired language impairments are linked to deficits on a categorization task that did not require making any verbal responses. The link between categorization and naming impairments was obtained regardless of the lesion that is presumably responsible for the naming impairments. These results add to the claim that language supports extra-communicative cognitive functions (Clark, 1998; see also Baldo et al., 2010), and that it may reify conceptual categories.

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Supplementary data

Supplementary data associated with this article can be found, in the on-line version, at <http://dx.doi.org/10.1016/j.cortex.2012.06.006>.

⁵ A productive line of future inquiry may be to employ patient samples larger than the present one (e.g., Kemmerer et al., 2012) and examine whether the patterns of associations between naming impairments, task performance and lesion sites, can be additionally explained by taking into account the degree of cognitive control/selective attention called on by the task.

REFERENCES

- Ashby FG, Queller S, and Berretty PM. On the dominance of unidimensional rules in unsupervised categorization. *Perception & Psychophysics*, 61(6): 1178–1199, 1999.
- Baayen RH, Davidson DJ, and Bates DM. Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, 59(4): 390–412, 2008.
- Baddeley AD, Chincotta D, and Adlam A. Working memory and the control of action: Evidence from task switching. *Journal of Experimental Psychology: General*, 130(4): 641–657, 2001.
- Balaban MT and Waxman SR. Do words facilitate object categorization in 9-month-old infants? *Journal of Experimental Child Psychology*, 64(1): 3–26, 1997.
- Baldo JV, Bunge SA, Wilson SM, and Dronkers NF. Is relational reasoning dependent on language? A voxel-based lesion symptom mapping study. *Brain and Language*, 113(2): 59–64, 2010.
- Bowerman M and Choi S. Shaping meanings for language: Universal and language-specific in the acquisition of spatial semantic categories. In Bowerman M and Levinson SC (Eds), *Language Acquisition and Conceptual Development*. Cambridge, UK: Cambridge University Press, 2001: 475–511.
- Bozeat S, Lambon-Ralph MA, Patterson K, Garrard P, and Hodges JR. Non-verbal semantic impairment in semantic dementia. *Neuropsychologia*, 38(9): 1207–1215, 2000.
- Caramazza A, Berndt RS, and Brownell HH. The semantic deficit hypothesis – Perceptual parsing and object classification by aphasic patients. *Brain and Language*, 15(1): 161–189, 1982.
- Casasola M. Can language do the driving? The effect of linguistic input on infants' categorization of support spatial relations. *Developmental Psychology*, 41(1): 183–192, 2005.
- Clark A. Magic words: How language augments human computation. In Carruthers P and Boucher J (Eds), *Language and Thought: Interdisciplinary Themes*. New York, NY: Cambridge University Press, 1998: 162–183.
- Cohen R, Kelter S, and Woll G. Analytical competence and language impairment in Aphasia. *Brain and Language*, 10(2): 331–347, 1980.
- Cohen R, Woll G, Walter W, and Ehrenstein H. Recognition deficits resulting from focussed attention in aphasia. *Psychological Research*, 43(4): 391–405, 1981.
- Cragg I and Nation K. Language and the development of cognitive control. *Topics in Cognitive Science*, 2(4): 631–642, 2010.
- Davidoff J and Roberson D. Preserved thematic and impaired taxonomic categorisation: A case study. *Language and Cognitive Processes*, 19(1): 137–174, 2004.
- De Renzi E and Spinnler H. Impaired performance on color tasks in patients with hemispheric damage. *Cortex*, 3(2): 194–217, 1967.
- Dunbar K and Sussman D. Toward a cognitive account of frontal lobe function: Simulating frontal lobe deficits in normal subjects. *Annals of New York Academy of Sciences*, 769: 289–304, 1995.
- Emerson MJ and Miyake A. The role of inner speech in task switching: A dual-task investigation. *Journal of Memory and Language*, 48(1): 148–168, 2003.
- Fodor JA. *The Language of Thought*. 1st ed. Cambridge, MA: Harvard University Press, 1975.
- Goldstein K. Das Wesen der amnestischen Aphasie. *Schweizer Archiv für Neurologie und Psychiatrie*, 19: 163–175, 1924.
- Goldstein K. *Language and Language Disturbances*. New York: Grune & Stratton, 1948.
- Hjelmquist EKE. Concept-formation in non-verbal categorization tasks in brain-damaged patients with and without Aphasia. *Scandinavian Journal of Psychology*, 30(4): 243–254, 1989.
- Holmes CJ, Hoge R, Collins L, Woods R, Toga AW, and Evans AC. Enhancement of MR images using registration for signal averaging. *Journal of Computer Assisted Tomography*, 22(2): 324–333, 1998.
- Jackson H. On afflictions of speech from disease in the brain. *Brain*, 1: 304–330, 1878.
- James W. *Principles of Psychology*, vol. 1. New York: Holt, 1890.
- Jefferies E, Patterson K, and Lambon-Ralph MA. Deficits of knowledge vs. executive control in semantic cognition: Insights from cued naming. *Neuropsychologia*, 46(2): 649–658, 2008.
- Kan IP and Thompson-Schill SL. Selection from perceptual and conceptual representations. *Cognitive, Affective, & Behavioral Neuroscience*, 4(4): 466–482, 2004.
- Kemmerer D, Rudrauf D, Manzel K, and Tranel D. Behavioral patterns and lesion sites associated with impaired processing of lexical and conceptual knowledge of actions. *Cortex*, 48(7): 826–848, 2012.
- Koemeda-Lutz M, Cohen R, and Meier E. Organization of and access to semantic memory in Aphasia. *Brain and Language*, 30(2): 321–337, 1987.
- Li P and Gleitman L. Turning the tables: Language and spatial reasoning. *Cognition*, 83(3): 265–294, 2002.
- Lupyan G, Mirman D, Hamilton RH, and Thompson-Schill SL. Categorization is modulated by transcranial direct current stimulation over left prefrontal cortex. *Cognition*, 124(1): 36–49, 2012.
- Lupyan G, Rakison DH, and McClelland JL. Language is not just for talking: Labels facilitate learning of novel categories. *Psychological Science*, 18(12): 1077–1082, 2007.
- Lupyan G and Spivey MJ. Redundant spoken labels facilitate perception of multiple items. *Attention, Perception, & Psychophysics*, 72(8): 2236–2253, 2010.
- Lupyan G and Swingle D. Self-directed speech affects visual search performance. *The Quarterly Journal of Experimental Psychology*, 65(6): 1068–1085, 2012.
- Lupyan G. The conceptual grouping effect: Categories matter (and named categories matter more). *Cognition*, 108(2): 566–577, 2008.
- Lupyan G. Extracommunicative functions of language: Verbal interference causes selective categorization impairments. *Psychonomic Bulletin & Review*, 16(4): 711–718, 2009.
- Lupyan G. What do words do? Towards a theory of language-augmented thought [Online]. In Ross BH (Ed), *The Psychology of Learning and Motivation*. Academic Press: 255–297, <http://www.sciencedirect.com/science/article/pii/B9780123942937000078>; 2012a.
- Lupyan G. Linguistically modulated perception and cognition: The label-feedback hypothesis. *Frontiers in Psychology*, 3(54). <http://dx.doi.org/10.3389/fpsyg.2012.00054> 2012b.
- Miyake A, Emerson MJ, Padilla F, and Ahn JC. Inner speech as a retrieval aid for task goals: The effects of cue type and articulatory suppression in the random task cuing paradigm. *Acta Psychologica*, 115(2–3): 123–142, 2004.
- Noppeney U and Wallech CW. Language and cognition – Kurt Goldstein's theory of semantics. *Brain and Cognition*, 44(3): 367–386, 2000.
- Novick JM, Trueswell JC, and Thompson-Schill SL. Broca's area and language processing: Evidence for the cognitive control connection. *Language and Linguistics Compass*, 4(10): 906–924, 2010.
- Roach A, Schwartz MF, Martin N, Grewal RS, and Brecher A. The Philadelphia naming test: Scoring and rationale. *Clinical Aphasiology*, 24: 121–133, 1996.
- Roberson D, Davidoff J, and Braisby N. Similarity and categorisation: Neuropsychological evidence for a dissociation in explicit categorisation tasks. *Cognition*, 71(1): 1–42, 1999.
- Rossion B and Pourtois G. Revisiting Snodgrass and Vanderwart's object pictorial set: The role of surface detail in basic-level object recognition. *Perception*, 33(2): 217–236, 2004.

- Schwartz MF, Brecher A, Whyte J, and Klein MG. A patient registry for cognitive rehabilitation research: A strategy for balancing patients' privacy rights with researchers' need for access. *Archives of Physical Medicine and Rehabilitation*, 86(9): 1807–1814, 2005.
- Schwartz MF, Kimberg DY, Walker GM, Faseyitan O, Brecher A, Dell GS, et al. Anterior temporal involvement in semantic word retrieval: Voxel-based lesion-symptom mapping evidence from aphasia. *Brain*, 132(12): 3411–3427, 2009.
- Semenza C, Bisiacchi PS, and Romani L. Naming disorders and semantic representations. *Journal of Psycholinguistic Research*, 21(5): 349–364, 1992.
- Sloutsky VM. From perceptual categories to concepts: What develops? *Cognitive Science*, 34(7): 1244–1286, 2010.
- Snyder HR, Feigenson K, and Thompson-Schill SL. Prefrontal cortical response to conflict during semantic and phonological tasks. *Journal of Cognitive Neuroscience*, 19(5): 761–775, 2007.
- Thompson-Schill SL, D'Esposito M, Aguirre GK, and Farah MJ. Role of left inferior prefrontal cortex in retrieval of semantic knowledge: A reevaluation. *Proceedings of the National Academy of Sciences U.S.A.*, 94(26): 14792–14797, 1997.
- Vignolo LA. Disorders of conceptual thinking in aphasia. In Denes G and Pizzamiglio L (Eds), *Handbook of Clinical and Experimental Neuropsychology*. Hove: Psychology Press, 1999: 273–288.
- Waldron EM and Ashby FG. The effects of concurrent task interference on category learning: Evidence for multiple category learning systems. *Psychonomic Bulletin & Review*, 8(1): 168–176, 2001.
- Walker GM, Schwartz MF, Kimberg DY, Faseyitan O, Brecher A, Dell GS, et al. Support for anterior temporal involvement in semantic error production in aphasia: New evidence from VLSM. *Brain and Language*, 117(3): 110–122, 2011.
- Wayland S and Taplin JE. Nonverbal categorization in fluent and non-fluent anomic Aphasics. *Brain and Language*, 16(1): 87–108, 1982.
- Whitehouse P, Caramazza A, and Zurif E. Naming in Aphasia – Interacting effects of form and function. *Brain and Language*, 6(1): 63–74, 1978.
- Yoshida H and Smith LB. Linguistic cues enhance the learning of perceptual cues. *Psychological Science*, 16(2): 90–95, 2005.