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REPORT

Developmental changes in information central to artifact representation: evidence from 'functional fluency' tasks

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Abstract

Research suggests that while information about design is a central feature of older children's artifact representations it may be less important in the artifact representations of younger children. Three experiments explore the pattern of responses that 5- and 7-year-old children generate when asked to produce multiple uses for familiar (Experiments 1, 2) and novel (Experiment 3) named objects. Results showed that while older children tended to produce responses based on the known design function of the object, younger children's responses were more flexible, though still constrained by the mechanical structure of the object. Only when ignorant of a novel object's design function did older children produce more varied functions than did younger children. These results suggest that representations supporting object function undergo change across this period of development, with information about design assuming more importance later than it does earlier.

Introduction

Mounting research in cognitive science has focused on how knowledge about artifacts and their functions is represented, how it is acquired, and whether these representations undergo change across development (e.g. German, Truxaw & Defeyter, 2007; chapters in Laurence & Margolis, in press). Adult reasoning about artifacts appears to be guided by the assumption that original intentions of the *designer* are a critical determinant of an artifact's category and/or function (Dennett, 1987; Bloom, 1996; Kelemen, 1999; Rips, 1989; Matan & Carey, 2001).

A key question for theories of the acquisition of artifact concepts is the availability of information relevant to an artifact's function. Some information about mechanical properties may be perceived directly (e.g. Gibson, 1979; Vaina, 1983). Children may learn the typical function of an artifact by observing its use by others (Abravanel & Gingold, 1985; Casler & Kelemen, 2005, 2007). However, knowledge of design is more complicated: it is based on historical facts about the creation of the object, and requires understanding the difference between the goal of creating an object and the goal that the object is created to fulfil. It seems unlikely that explicit knowledge of design contributes to the early development of artifact knowledge (Defeyter & German, 2003; German & Johnson, 2002). Thus, most cognitive developmental analysis suggests that rather than supported by explicit understanding of design, early artifact function knowledge reflects the integration of output of 'core knowledge' systems specialized for reasoning about objects' mechanical structure and the goals of the agents that use them (Leslie, 1994).

Within this approach, there has been considerable debate about when, during development, information about original design begins to assume greater importance in children's artifact representations. Some theorists argue that reasoning about object functions is based on information about design from about age 4 or earlier (Kelemen, 1999; Kemler Nelson, Herron & Morris, 2002; Diesendruck, Markson & Bloom, 2003); others propose that design information becomes important somewhat later, around 6 years of age (Defeyter & German, 2003; Matan & Carey, 2001; German & Defeyter, 2000; German & Johnson, 2002; Gentner, 1978; Landau, Smith & Jones, 1998; Truxaw, Krasnow, Woods & German, 2006). Nevertheless, there is general agreement that semantic memory for artifacts and their functions may be weighted more toward different sources of information as children grow older.

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The majority of developmental studies in this domain employ tasks where children judge the function or category of novel or familiar objects. However, two recent studies showed a developmental change in insight problem solving, where an object must be employed in an atypical manner to solve a problem (Defeyter & German, 2003; German & Defeyter, 2000). In function-based insight problems, demonstrating the design function of an object during the problem's presentation (e.g. if a box is presented *containing* items) causes subjects to be impaired in selecting it for an alternative use (e.g. *as a support*; Duncker, 1945; German & Barrett, 2005), a phenomenon known as 'functional fixedness'. Older children, who know the conventional function of a box is for containment, show functional fixedness. Younger children, where by hypothesis, the design function is no more important than other plausible functions, were better at solving the problem in the condition where the function was demonstrated than were older children (Defeyter & German, 2003; German & Defeyter, 2000).

In the current series of studies, further evidence for changes in the representation of artifact concepts is provided using a new paradigm. This paradigm requires individuals to generate multiple different functions for familiar objects – and is based on tests of so-called 'divergent thinking' (Guildford, 1950; Hudson, 1966; Mouchiroud & Lubart, 2001).[1] This task can be considered a variant of semantic verbal fluency, which developmentally shows typical age-related improvement as might be expected for a task used to measure executive functions such as planning, inhibition and switching (Riva, Nichelli & Devoti, 2000).

The idea that information central to artifact representations becomes weighted toward design across development generates a simple prediction about the *nature* of the functions generated in this task (dubbed the 'functional fluency' task) by individuals whose semantic memory systems represent function information in different ways. If design information is central to an individual's artifact representation then we might expect responses to be organized around information about its design. By contrast, a different pattern of responses might emerge in individuals where design is less important. In particular, we might expect fewer responses based on the design function than in the older case (which, for younger children, according to our developmental hypothesis, is one function among many), and more flexible functions based on goals supported by other mechanical properties of the object.

[1] For discussion of the application of this task as a test of 'creativity' see Runco (1992).

Experiment 1

Method

Subjects

Twenty 5-year-olds (12 girls and 8 boys, mean age 5–0, range 4–7 to 5–5) and 20 7-year-olds (10 girls and 10 boys, mean age 7–2, range 6–9 to 7–5) participated. Children were recruited from schools serving a variety of social backgrounds in an urban UK area. All children spoke English as a first language.

Materials and procedure

Four coloured pictures of familiar artifacts (a brick, a paperclip, a wooden barrel, and a blanket) were laminated onto white card. Each card measured 15.5 cm long by 11.2 cm high (see Figure 1).

Children were tested individually in a quiet area of the classroom. The four 'functional fluency' tasks were presented in a fixed order: brick, paperclip, barrel, and blanket. On each trial a picture card of one of the familiar objects was presented and children were told the name of the artifact, before being asked to generate multiple functions for that object. For example, 'See this. (*point to brick picture*.) Please can you tell me as many different things that you can use this for within one minute. Are you ready? Go.' After one minute had elapsed the picture card was removed from the desktop and the next trial commenced.

Results and discussion

First, the total number of functions for each object was obtained by applying the following criteria to each response. (1) The novel function should be mechanically plausible. (2) The artifact would *not* be changed permanently by the use (e.g. breakage). (3) Any action performed on the object must have an end goal (e.g. roll a barrel *to transport toys*) not merely a change of location, orientation, or movement (e.g. 'roll it', 'push it' were not counted). (4) Any novel function for an object must be related to the mechanical properties and/or shape of the object (e.g. using a brick to keep a door open, using a paperclip as a hair slide). Repetitions of the same function were excluded.

From this total number, a subscore was generated which comprised the number of functions based on the *design function* of the object. This score was made up of each plausible function involving an extension of the design function. Thus in the case of the brick, the responses 'building a house', 'building a school' would

Figure 1 *Familiar artifacts used for the functional fluency task in Experiment 1 and Experiment 2.*

Table 1 *Mean function scores according to age, with 'design function' and 'novel function' subscores for children in Experiments 1 and 2 (SDs in parentheses)*

		Total functions (SD)	Design functions (SD)	Novel functions (SD)
Experiment 1	5-year-olds	8.05 (3.93)	5.20 (3.27)	2.85 (2.62)
	7-year-olds	9.65 (3.69)	8.40 (3.39)	1.25 (1.25)
Experiment 2	5-year-olds	8.25 (2.92)	5.0 (2.68)	3.25 (2.34)
	7-year-olds	6.30 (2.83)	5.5 (2.95)	0.80 (0.89)

be counted as two design functions. The other 'novel function' subscore reflected the functions that were unrelated to the design function and thus were deemed 'novel'.[2]

All children's responses were coded by one of the authors and another coder, blind to the hypotheses under test and to the age of the children. The agreement between the scorers assigning responses to each category was satisfactory (88%, $K = .77$), and disagreements were resolved through discussion. The scores for the four objects were added to produce a composite set of scores across all objects.

[2] Cases where novel functions were simply repeated were excluded from both the total and the novel function scores.

The results of this analysis appear in Table 1. These results indicate that while there was no overall difference in the total function score between younger and older children ($U = 142.5$, *ns*), the relative frequencies of the two types of function interacted with age. Seven-year-old children generated more design functions than did 5-year-olds, $U = 81.5$, $p < .001$, whereas 5-year-old children generated more novel functions than 7-year olds, $U = 107.5$, $p < .01$.

The results of Experiment 1 showed that older children's generation of multiple uses for familiar objects is based mostly on their knowledge of the object's design. Younger children also produced design functions in response to this question, though they produced fewer than did the older children. However, the younger children also produced more responses that extended the use beyond variations on the design function to goals that were quite different. Note that because the design function, named at the outset of the procedure, was counted among the responses, it was not a surprise that younger children generated more design functions than novel functions. This indicates that even for younger children, the design function is represented as part of the artifact's conceptual structure, just as might be expected given children's knowledge of the everyday functions of objects, and the early origin of this knowledge (Abravanel & Gingold, 1985; Casler & Kelemen, 2005, 2007; Gauvain & Greene, 1994).

In Experiment 2, we address one obvious alternative account for the pattern of children's responses seen in Experiment 1. It is possible that older children did not generate novel responses in this task because they interpret the task differently. Perhaps older children are sophisticated enough to generate both design and novel functions – but report only design functions, not realizing that novel functions are acceptable. In Study 2, we address this possibility by presenting children with different instructions. Here children were presented with the objects, as before, but were also presented with information both about the design function of the object and an alternative (non-design-related) function, before being asked to generate more possible uses. This way, the children received explicit instructions that atypical functions were acceptable responses.

If older children's failure to generate novel functions in Experiment 1 arose because they considered such responses illegitimate, then the new instructions should result in them switching to generate more novel functions characteristic of the younger group. However, if older children generated design functions as a result of the structure of their artifact concepts being based on design (and activated by previous responses), then we should not expect an increase in novel function responses. Indeed, we might even see a reduction in the total number of functions produced.

Experiment 2

Method

Subjects

Twenty 5-year-olds (10 boys, 10 girls, mean age 5–1, range 4–7 to 5–3) and 20 7-year-olds (11 boys, 9 girls, mean age 6–10, range, 6–6 to 7–3) participated. Children were recruited from schools serving a variety of social backgrounds in an urban area of the UK. All children spoke English as a first language and none had participated in Experiment 1.

Materials and procedure

The materials for this study were identical to those used in Experiment 1. The procedure was identical to that reported for Study 1 except that the children were given information about the conventional function as well as an example of a possible alternative use (selected from among the qualifying novel responses in Experiment 1) to prime their later responses in the task: 'See this brick. It could be used for building houses, but it might also be used to hold open the door in the wind. Can you think of as many other things that you could use this brick for in one minute? Go.'

Results and discussion

The results of this study were scored according to the same criteria employed in Study 1. Children's novel response score, however, was *not* incremented for responses that matched the example novel function described in the instructions; the responses had to be both different from the conventional and the example novel response to count. Once again, agreement scores were calculated to ensure that coder agreement was good (93%, $K = .84$).

The results appear in Table 1, and reveal that in this study, 5-year-olds actually produced marginally more total functions than did 7-year olds ($U = 129$, $p = .053$). Analysis of the subcategories indicated that this resulted from reduced design function responses among older children; here, 5- and 7-year-old children did not differ in their production of design functions, unlike Study 1 ($U = 174.5$, *ns*). Younger children continued to produce significantly more novel functions than their older peers, replicating study 1 ($U = 60.5$, $p < .001$).

In comparison to Experiment 1, older children generated fewer variations on the design function of the object. This suggests that in the previous experiment they interpreted the initial task as one in which design functions were required. However, the inclusion of an example novel function did *not* result in additional novel functions being generated by these children, suggesting that rather than *selecting* proper functions to report having generated both design and atypical functions, they experienced difficulty in producing more flexible functions when the standard route to generating alternative uses was blocked. This is predicted by theories in which 'design' information is better integrated into the artifact representations of older children than in those of younger children (Defeyter & German, 2003; German & Defeyter, 2000; German & Johnson, 2002; Kelemen, 1999; Matan & Carey, 2001).

So far, the investigation has centred on the case where known function information might constrain responses in a function generation task. One additional test of the importance of this function information would to be compare a case where children have such information with one where they do not. If children are presented with novel objects – the design functions of which they have no knowledge – then we should expect their responses to be based solely on the mechanical properties of the objects and their knowledge of the relationship between these properties and goals that might be served by them. Critically, under these circumstances, there are no reasons to suppose older children to be any worse than younger children. If anything, they should be better. However, if design information is more important to older than younger children, adding such information should constrain the responses of older children more than it does those of younger children.

Experiment 3

Method

Subjects

Forty children were pseudo-randomly assigned to either the function demonstration (20 5-year-olds; 8 girls and 12 boys, mean age 5–1, range 4–7 to 5–4, and 20 7-year-olds; 10 girls and 10 boys, mean age 7–2, range 6–8 to 7–3), and 40 to the no function demonstration condition (20 5-year-olds; 13 girls and 7 boys, mean age 5–4, range 5–2 to 5–6, and 20 7-year-olds; 10 girls and 10 boys, mean age 7–3, range 6–9 to 7–5). All participants spoke English as a first language and none of the children had participated in Experiments 1 or 2.

Materials and procedure

The test objects comprised a Perspex cylinder with hinged lid (12 cm long × 2.5 cm internal diameter), a wooden ‘T-shaped’ object made from wood (15.5 cm long, 11.0 cm wide × 3.0 cm diameter), a metal ‘clip’ (11.0 cm long) with an attached piece of flexible plastic (4.0 cm long), and a circular cloth (24.0 cm diameter) weighted around the circumference with beads sewn into the hem. Additional props included a piece of modelling clay (5.0 cm long × 0.5 cm high), four small marbles, two small pinecones, and a picture card (8.5 cm long × 6.0 cm wide). A doll measuring 16 cm was used as the story character.

Children were tested individually in an empty classroom. They were seated opposite the experimenter at a low table.

Function demonstration condition. On each trial the test object was named and children were taught the intended function for the test object. For example, the experimenter held up the T-shaped object saying ‘See this Bif. Billy made this Bif for rolling out playdoh.’ The experimenter demonstrated the intended function by rolling out the modelling clay with the Bif. Then the Bif was placed in the centre of the table (the playdoh was removed) and children were asked, ‘What else could Billy use this Bif for?’ After 3 minutes had elapsed the experimenter held up the test object and asked children a control question: ‘What did Billy make this Bif for?’ The intended functions described for the other three objects are shown in Figure 2.

No function demonstration condition. Children were presented with the same named objects as described above, but no function demonstration was given. Children were simply presented with the objects and given 3 minutes in which to produce as many responses as they could think of: ‘See this Bif. Billy made this Bif. What do you think Billy might have made this Bif for?’

Results and discussion

The general criteria for plausible functions established for prior studies were used. There was only one category of response for the no function demonstration condition since no design function was presented to these children. For the function demonstration condition, the total number of functions generated was divided into two categories: ‘design functions’, which were extensions of the newly introduced design function in the manner described for Study 1; and ‘novel functions’ which were those functions unrelated to the design function. The same two coders were used and coder agreement was calculated to be good (90%, $K = .80$), with disagreements again resolved by discussion.

The results appear in Table 2, and show first that in terms of the total function score, there were no differences between the children in the function demonstration condition, $t(38) = -.167$, *ns.* By contrast, in the condition where no information about function was provided, the results showed that 7-year-olds generated more functions than did the 5-year-olds, $t(38) = 5.47$, $p < .001$. This suggests that older children are perfectly capable of producing plausible functions for simple novel objects, and do so more effectively than do younger children.

However, this pattern does not hold in the function demonstration condition, where the overall lack of difference in functions generated is revealed to emerge from qualitatively different types of function response in each age group, with 5-year-olds generating more *novel function* responses compared to 7-year-olds, $t(38) = 4.91$, $p < .001$,

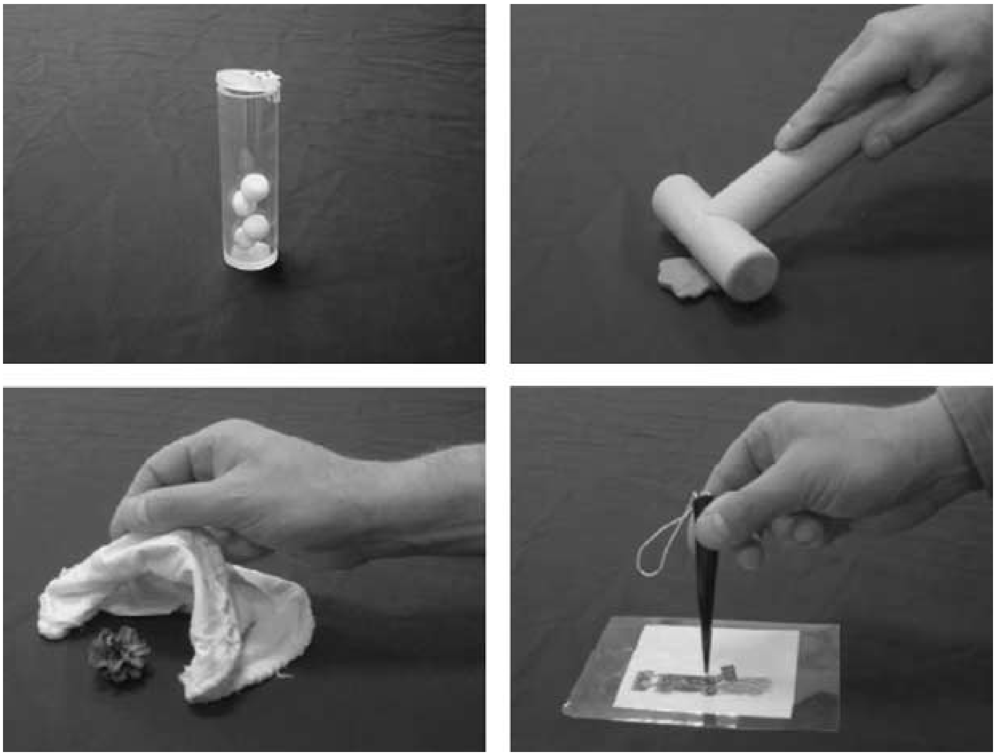

Figure 2 *Novel objects and demonstrated functions in Experiment 3. The objects were (clockwise from top left) the 'tog' (holding marbles), the 'bif' (rolling playdoh), the 'fep' (hanging pictures) and the 'zig' (covering pinecones).*

Table 2 *Mean function generation scores, according to age and condition, with design and novel function subscores for function demonstration condition in Experiment 3 (SDs in parentheses)*

		Total functions (SD)	Design functions (SD)	Novel functions (SD)
5-year-olds	Function demo	12.65 (3.54)	5.70 (3.42)	6.95 (3.50)
	No function	4.70 (1.42)		
7-year-olds	Function demo	12.85 (4.37)	10.60 (5.52)	2.25 (2.47)
	No function	9.35 (3.43)		

and 7-year-olds generating more functions based upon the intended function than did 5-year-olds, $t(38) = 3.51$, $p < .001$. This replicates the pattern observed in Studies 1 and 2.[3]

Finally, all children correctly answered the control questions by stating the design function. This rules out the possibility that differences in responses in this condition were the result of children forgetting the demonstrated function.

[3] Parametric tests are presented here because the scores meet the requirements for normally distributed data. Non-parametric tests (e.g. Mann-Whitney *U*) reveal identical results.

General discussion

Adult representation of artifact concepts appears to be strongly influenced by information about the design function of the object (German & Johnson, 2002; Rips, 1989; Kelemen, 1999). We propose that young children's representations are initially less sensitive to this information, and instead are based on more readily available information that is the output of early and reliably developing separate 'core' knowledge systems (Spelke & Kinzler, 2007) representing object mechanics on the one hand and social agency on the other. There is abundant independent evidence for such systems (e.g. Leslie, 1994). Across development, information about design becomes more important in artifact representation – a conclusion supported by mounting evidence using categorization tasks (Defeyter, German & Hearing, in press; Jaswal, 2006; Matan & Carey, 2001), function judgment tasks (Defeyter *et al*., under review; German & Johnson, 2002; Kelemen, 1999) and problem-solving tasks (Defeyter & German, 2003; German & Defeyter, 2000).

In the current series of experiments further evidence for this developmental change was generated in a new task based on tests of divergent thinking in which participants were required to generate multiple functions for familiar and novel objects. The results showed that for older children, responses were likely to be based on extensions of the known design function of the object. For younger children, while the design function of the object was also often generated, more responses were generated that were not so constrained, but that were instead based on novel uses of the artifact. This result held for familiar objects (Experiments 1 and 2) and extended to the case of novel objects (Experiment 3).

To what extent are these results explicable in terms of general developmental changes occurring at about this age? Perhaps older children conform more readily to 'rules' that decrease their tendency to offer atypical functions. Alternatively, perhaps older children's more sophisticated pragmatic understanding renders them likely to assume that the function they hear about early in the procedure (Experiment 3) must be important and so they generate responses accordingly. However, note first that similar patterns of novel function generation were produced by older children under conditions where the design function was not mentioned at all (Study 1) and when it was (Study 2), and further that older children's function responses were *not* based on extensions of the *alternative* function mentioned by the experimenter (Study 2); if drawing attention to a specific function were responsible for the generation of functions based on that function, then more such responses should have been produced in Study 2 than Study 1, whereas the actual effect of highlighting the design function was to *reduce* this response type.

Taken together, the results of the three experiments reported here add to the mounting evidence, from a variety of laboratories and using a variety of methods, that point to developmental change in the information that is central to artifact representation, with information about design assuming a more critical role as children get older. Though there may be agreement that there is developmental change across this period, the exact nature of that developmental change is still unclear. One possibility is that there is something akin to 'conceptual change' – a radical shift in conceptual structure in which one kind of understanding gives way to another very different structure. Matan and Carey (2001) propose this kind of explanation to account for changes in artifact categorization between ages 4 and 6, pointing to the possibility that the emergence of a 'design stance' occurs at about this time, with reasoning by analogy from an understanding of design in the domain of folk biology playing a causal role.

An alternative possibility is that the change from artifact representations based on information about mechanical structure and goals gradually gives way to representations in which the design function assumes a more important, integrated role, with no sudden shift from one kind of conceptual structure to the other. For example, German and Johnson suggest that information about design might only gradually assume more importance in artifact representations when children have sufficient processing resources to parse first-order from second-order mental states (2002, p. 297; see also Defeyter & German, 2003, p. 151).

To elaborate briefly on this proposal, the idea is that in representational terms, information that an object was 'made for' a given purpose has a hierarchical and dual nature. One element is an intention on the part of the designer (to make an object), which must be segregated from the intention concerning the use to which the object will eventually be put. For children to attend to the designer as a more important social agent than other users, *both* elements of the 'made for' information must be represented. German and Johnson's (2002) proposal was that this could be thought of as involving a recursive intention representation, as in: '*maker* intends that "*user* intends that *x*"', and that such representational formats were only readily handled by children with sufficient processing resources to deal with recursive mental state representations. Developmentally, this is likely to be reflected as a gradually improving ability to attend to the relevant design information, rather than a sudden shift, as is the case in other developmental change that stems from increased processing resources (e.g. solving false belief problems; see e.g. Leslie, Friedman & German, 2004; Yazdi, German, Defeyter & Siegal, 2006).[4]

There is currently no evidence that can decide between the 'conceptual shift' and 'gradual change' possibilities.

[4] Note that under circumstances when processing demands are reduced, children younger than 6 succeed at second-order mental state reasoning (e.g. Sullivan, Zaitchik & Tager-Flusberg, 1994). However, the proposal here is not that children younger than 6 *cannot* represent a second-order intention of the designer (see, for example, interpretations in Kelemen, 2004, pp. 298–299; Kelemen & Carey, in press), but rather that owing to the differential processing demands of first- versus second-order goals, the goal of the (eventual) user 'overshadows' children's attention to the importance of the maker's intention (to create the object).

Defeyter and German (2003) demonstrated that the advantage in problem-solving that younger children enjoy in insight problems where design functions are demonstrated extends to a case where novel objects are employed. This suggests that the change toward design-based information as important for artifact concepts is not based on familiarity with *specific artifacts with known functions*. Nonetheless, this finding does not demonstrate that design information becomes important by virtue of a conceptual shift – the importance of design may still become gradually integrated across development.

Whatever the outcome of further research into the mechanisms supporting change in the information that is central to artifact representations across development, the current results indicate an interesting interaction between children's knowledge in a particular domain (here, artifact concepts) and a task (semantic fluency) that is often considered a measure of general executive function, with concordant improvement across age (Riva *et al*., 2000) or a test of creative divergent thinking (Runco, 1992). Here, we show that as with other problem-solving tasks (Duncker, 1945), it is important to consider both the domain of the content of the problem as well as the general processes that might be implicated. Changes in development in the information central to artifact representations, shown to constrain the deployment of knowledge in novel tool use problems (Defeyter & German, 2003), also appear to constrain their generation of responses in this variety of semantic fluency task.

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