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Sensitivity and salience of form–function correlations of objects: Evidence from feature tasks

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Abstract The present research evaluates the sensitivity and salience of form–function correlations in contrast with other types of feature correlations (function–function, form–form) in adults and using real object features (from tools and utensils). In Experiment 1, the participants judged the relation between the form and function features of tools. In Experiment 2, participants were asked to generate a second feature related to a given form or function feature. In Experiment 3, participants were asked to make a lexical decision in which form and function features were used as primes and targets. The results showed that even though participants were sensitive to form–function correlations, these were not particularly salient when compared with other feature-type correlations, notably function–function correlations. Our data underline the overall importance of function information to object representations and the impact of the statistical co-occurrence of features when processing object features.

Keywords Concepts · Semantic memory · Form–function correlations

In their seminal work on the representation of natural categories, Rosch, Mervis, Gray, Johnson, and Boyes-Braem (1976) called our attention to feature correlations, proposing that features of real-world objects do not occur independently of each other and that combinations or co-occurrences of features are not all equally probable. These ideas have been empirically supported by studies using feature generation or listing tasks, in which participants are asked to write down all of the features they remember for a given concept and feature lists for each concept are then assembled across participants. Studies of speaker-generated feature norms have shown that features are differentially correlated with each other across concepts and within the same concept (e.g., Cree & McRae, 2003; Garrard, Lambon Ralph, Hodges, & Patterson, 2001; McRae, de Sa, & Seidenberg, 1997; Vinson, Vigliocco, Cappa, & Siri, 2003; Zannino, Perri, Pasqualetti, Caltagirone, & Carlesimo, 2006).

Studies using artificial and natural categories have also shown that people are sensitive to these "statistical" correlations when they learn or process concepts (e.g., Chin-Parker & Ross, 2002; McRae, Cree, Westmacott, & de Sa, 1999; McRae et al., 1997; Wattenmaker, 1991, 1993), an ability that is found early in infancy (e.g., Younger & Cohen, 1986). However, the detection and use of "statistical" correlations of features is not a universal phenomenon (e.g., Malt & Smith, 1984; Murphy & Wisniewski, 1989). It depends on the tasks and materials employed, which are particularly important to performance on speeded online tasks (e.g., McRae et al., 1999; McRae et al., 1997; Wattenmaker, 1991), and seems to be used implicitly rather than explicitly (e.g., Wattenmaker, 1991).

Rosch (1977) also proposed the idea that people could be ignorant of some correlational structures while exaggerating others. Specifically, people tend to notice statistical correlations more when they are knowledge based or justified than when they are arbitrary (Malt & Smith, 1984; Medin, Altom, Edelson, & Freko, 1982; Murphy & Medin, 1985).

Murphy and Medin (1985) argued that the extent to which people will notice feature correlations is related to their prior expectations that reflect their intuitive theories of the world. Accordingly, studies with both adults and young children have shown a particular sensitivity to these

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knowledge-based correlations (e.g., Barrett, Abdi, Murphy, & Gallagher, 1993; Lin & Murphy, 1997; Madole & Cohen, 1995; McCarrell & Callanan, 1995; Medin et al., 1982). The use of knowledge-based correlations is also not universal, and it seems to be more important to performance on slower, offline tasks such as category or typicality judgements (e.g., Ahn, Marsh, Luhmann, & Lee, 2002; Barrett et al., 1993; Malt & Smith, 1984; McNorgan, Kotack, Meehan, & McRae, 2007).

Within the group of knowledge-based correlations, form–function correlations have received particular attention, and they are the main target of the present research. Form–function correlations reflect the fact that there is a close relationship between how things look and how we interact with those things. This is especially true for artefacts (Greif, Kemler Nelson, Keil, & Gutierrez, 2006; Stibel, 2006). Moreover, this relation is not arbitrary, but causally motivated (e.g., Bloom, 1996; German & Johnson, 2002; Keil, 1989). A designer's intention to create an object with a given function (e.g., one that can be used for cutting) causally constrains many of its structural properties (e.g., it must have blade, must be sharp, and must have a handle). From about two years of age, children seem to detect these form–function correspondences (e.g., Madole & Cohen, 1995; Madole, Oakes, & Cohen, 1993). Children attend to the causal relation between functional and perceptual features (Kemler Nelson, Russell, Duke, & Jones, 2000) and to the conventional and intended uses of objects (Diesendruck, Markson, & Bloom, 2003), and they make use of this information in the contexts of naming (Kemler Nelson et al., 2000) and inference (McCarrell & Callanan, 1995). In healthy adults, form–function correlations impact both category and typicality judgements (e.g., Lin & Murphy, 1997).

Tversky and Hemenway (1984) showed that the relationship between form and function is particularly salient in object parts that refer both to a perceptually identifiable segment and to a specialized function of the object. A privileged relationship between form and function in objects has also been proposed as a determinant of object-naming and mimic patterns in semantic memory impairments (e.g., Caramazza, Hillis, Rapp, & Romani, 1990; De Renzi & Lucchelli, 1994; Moss, Tyler, & Jennings, 1997). In particular, the fact that correlated properties support each other with mutual activation would make them more resistant to damage (Devlin, Gonnerman, Andersen, & Seidenberg, 1998). In this context, Moss, Tyler, and associates (Moss, Tyler, & Devlin, 2002; Moss et al., 1997; Tyler, Moss, Durrant-Peatfield, & Levy, 2000) specifically argued that for objects (of which tools would be the clearest example), a small set of distinctive form and function features are strongly correlated, and are therefore more resistant to damage, in comparison with concepts from other categories.

Considering this background, the main goal of the present article is to evaluate the importance of form–function correlations in relation to other types of feature correlations (form–form and function–function) in the representation of real objects. More specifically, we wish to contribute to the evaluation of the theoretical status given to form–function correlations, following the contention that this topic has not received an adequate empirical evaluation.

On the one hand, it may be that form–function correlations are not particularly important to concept representations. In fact, although the theoretical foundations for their importance are vast and diverse, the empirical support for this so far is very limited. Most evidence comes from studies with children and has featured artificial concepts in which these correlations were created and manipulated to assess their influence in categorical judgements (e.g., Kemler Nelson et al., 2000; Madole & Cohen, 1995; McCarrell & Callanan, 1995; see also Lin & Murphy, 1997, who used adults as participants but also employed artificial categories). However, these studies have not compared the importance of form–function correlations and other types of feature correlations and have not considered the possible contributions of their statistical counterparts (e.g., their intercorrelational strength). Moreover, artificial concepts may emphasize this particular type of correlation more than would be the case for real concepts, because of their use of simpler but arbitrary structure–function combinations (e.g., Madole et al., 1993; Younger & Cohen, 1986). In the case of Tversky and Hemenway's (1984) research with adults, the results showed that object parts are related to basic-level advantage and to typicality, but the results again do not allow us to assess the importance of parts in relation to other dimensions. The role of form–function correlations as a deterrent of semantic breakdown has also received little support, suggesting that these correlations may not serve as a major organizational factor of semantic memory (Cree & McRae, 2003). The analysis of speaker-generated feature norms has also failed to provide any strong evidence for the prevalence of form–function correlations in objects (e.g., Cree & McRae, 2003; Garrard et al., 2001; Vinson et al., 2003; Zannino et al., 2006).

On the other hand, it may be the case that the negative evidence so far has not provided a fair test of the particular status of these correlations. Specifically, the analysis of speaker-generated feature norms has shown that there are fewer form–function correlations than there are same-feature-type correlations (i.e., form–form or function–function). However, this finding does not inform us about the relative importance of all of these correlations in processing object concepts. It may be that form–function correlations, although fewer, are more accessible and are given more weight in concept representations; quantitative analysis from speaker-generated feature norms simply would not pick up such characteristics (as it only informs about whether one type of correlation is more common than other). Moreover, many form–function correlations also may not be considered because they are embedded in part features (Tversky & Hemenway, 1984). For example, when someone generates a part in a feature-listing task (e.g., "handle" for *hammer*), he or she may be generating at the same time a function (e.g., used for holding the hammer) and a form feature (e.g., the handle as a visual feature), but only the latter gets credited.

To resolve this dispute, we ran three experiments that directly addressed different types of feature correlations of real objects, independently of particular concepts. With this novel approach, we hoped to overcome the previous limitations of using artificial stimuli that might not have reflected the true salience of form–function correlations. Moreover, by using different tasks and a design that directly compared different types of feature correlations, we hoped to provide a fairer test of form–function correlations.

In the first experiment, participants were asked to judge the relationship between the form and function features of tools. In the second experiment, participants generated a feature that was related to a given form or function feature (of tools or utensils). The third experiment was based on a priming paradigm and a lexical decision task in which form and function features were used as primes and targets and priming effects were assessed within and between feature types.

Experiment 1

The goal of Experiment 1 was to evaluate the relative salience of form–function correlations in relation to form–form, function–function, and function–form correlations. We focused on the features of tools, in which form–function correlations are assumed to be more salient (Moss et al., 2002; Moss et al., 1997; Moss et al., 2000; Tyler et al., 2000), and employed a slower, offline task in which knowledge-based correlations are thought to be more important to performance, relative to other types of correlations (e.g., Ahn et al., 2002; Barrett et al., 1993; Malt & Smith, 1984). We also used real features of real objects (tools) and addressed feature correlations directly (i.e., independently of a particular concept) to avoid the possible biases of using artificial concepts or a specific real object. In this context, form features corresponded to external components or parts, while function features referred to the intended use of an object (i.e., what an object was used for).

Urdapilleta, Bernard, and Tijus (2004) proposed a paradigm to evaluate the implicative structure of features that we consider particularly useful to evaluate the nature of form–function correlations of objects in comparison to other types of feature correlations. In their study, participants responded to sentences describing the relation between two features A and B, such as, "if a concept has feature A, can it generally be said that it also has feature B?" Testing all possible combinations of nine features of birds, they showed that the features were judged as being independent (i.e., having one property did not imply having the other, and vice versa), as having a relation of implication (i.e., having A means having B, but not vice versa), or as having a relation of equivalence (i.e., having A means having B, and vice versa).

Using an adapted version of this paradigm, we explored the nature of form–function correlations. Specifically, we tested whether such correspondences are restricted to a particular direction (i.e., a relation of implication, where functions are inferred from perceptual features) or are instantiated in both directions (i.e., a relation of equivalence, where function is derived from form, and vice versa). Moreover, we directly compared form–function correlations with other types of correlations, such as form–form and function–function correlations, to assess whether the former assume a special status in object processing.

According to Moss, Tyler, and colleagues (e.g., Tyler et al., 2000; see also De Renzi & Lucchelli, 1994), form–function correlations should mainly have a relation of equivalence, since they are thought to be instantiated by links that support activation not only from form to function, but also in the reverse direction. In contrast, according to Caramazza et al. (1990), the association should mainly be of implication (form implicates function, but not the reverse). Importantly, both models predict that form–function correlations have a special status and are stronger than other feature-type correlations (namely, form–form and function–function correlations). Alternatively, it is plausible that form–function correlations are not stronger than other types of correlations and that judgements in this situation are based on the statistical co-occurrence of features (i.e., their intercorrelation strength or the degree of feature intercorrelation), as suggested by McRae and associates (McNorgan et al., 2007; McRae et al., 1999; McRae et al., 1997).

Method

Participants A group of 42 undergraduate students participated for partial fulfilment of an introductory psychology course requirement.

Materials Eight features of tools (i.e., from scissors, a hammer, etc.) were selected from the McRae et al. (2005) feature norms, half corresponding to visual-form features ("is sharp," "has a blade," "has a handle," and "has bristles") and half denoting functional features ("used for breaking things," "used for cleaning," "used for cutting," and "used for making holes"). The two groups of features were equated in terms of their mean production frequency, mean intercorrelational strength, and mean distinctiveness: respectively, $t(6) = 0.24$, $p = .82$; $t(6) = 0.86$, $p = .42$; and $t(6) = 1.45$, $p = .19$. These values were calculated from the norms of McRae, Cree, Seidenberg, and McNorgan (2005), based on their respective values in the different tool-like concepts (i.e., tools, kitchen utensils, and arms with blades) included in the norms (e.g., the production frequency value for the feature "is sharp" corresponded to the mean of all production frequency values for this feature in the different tool-like concepts). Four other features were also selected and included in the task ("is shiny," "is heavy," "is small," and "is useful") so that the nature of the features would not be evident to the participants.

Features were grouped into pairs using all possible combinations, in a total of 132 feature pairs. Each possible feature pair was inserted in a sentence frame that read "If an object has feature A, can it generally be said that it also has feature B?" (e.g., If an object is sharp, can it generally be said that it also is used for cutting?). Sentences were pseudorandomly organized into two blocks, such that sentences that shared the same feature pair (A + B and B + A) were presented in separate blocks. Since each participant responded to only one of the blocks, we avoided contamination of the responses from previously having answered to a given feature pair. In each block, sentences were presented in a random order. All materials were mounted and presented using the Superlab for Windows software.

Procedure Participants were randomly distributed across blocks and tested individually following the same instructions. The participants were presented with sentences on a computer screen with the general format "If an object has feature A, can it generally be said that it also has feature B?" and had to make yes/no decisions to each sentence. Each trial started with a warning signal (an asterisk) that appeared for 500 ms; then the first two parts of the sentence ("If an object has feature A" and "can it generally be said that") were presented in different lines, and the participants were instructed to press the "yes" button as soon as they had read both parts. The final part of the sentence ("it also has feature B?") was then presented in a line below the second part, and participants were instructed to respond as quickly as possible, "yes" or "no," on whether they agreed with the sentence. They answered via a two-button response box, with the preferred hand being attributed to the "yes" button and the other to the "no" button (right hand preferred by 97% of the participants).

Results and discussion

Data from 1 participant had to be discarded due to a technical failure to record the data ($n = 41$). For each of the 56 possible target feature pairs (12 pairs for function–function and form–form; 16 pairs for form–function and function–form), we calculated the percentage of "yes" answers, corresponding to the percentage of the judged association from feature A to feature B. The mean percentages of association are presented in Fig. 1, covering the four feature-type combinations. There were no differences in response times (RTs; mean across conditions = 2,270 ms) as a function of feature-type association [$F(1, 52) = 1.04$, n.s.; RTs for four of the feature pairs were not available, as the items were always judged to be independent].

A between-subjects one-way ANOVA was carried out with the type of feature combination as an independent variable and the mean percentage of association as the dependent variable. The results showed a main effect of feature type [$F(3, 52) = 3.00$, $MSE = .05$, $p < .05$], with a post hoc analysis (Tukey HSD test for unequal n) revealing that the effect corresponded to a significant difference between form–form correlations and form–function correlations (see Fig. 1).

We then analyzed the correlation between the percentage of association of each feature pair and its mean intercorrelational strength (both for each feature and for the sum of the two feature pairs). We found a small but significant correlation between the percentage of association and the intercorrelational strength of the first feature of the pair ($r = .27$, $p < .05$, $n = 56$), a result that indicated that judging the relation between two features was modulated by their statistical correlation. Finally, as can be seen from Fig. 1, the mean percentage of feature association was relatively low ($M = .29$), suggesting that, in general, feature pairs were judged to be independent more than associated.

While form–function correlations were the most salient type of feature association, the difference was significant only in comparison to form–form associations. Critically, when compared to other correlations involving functional

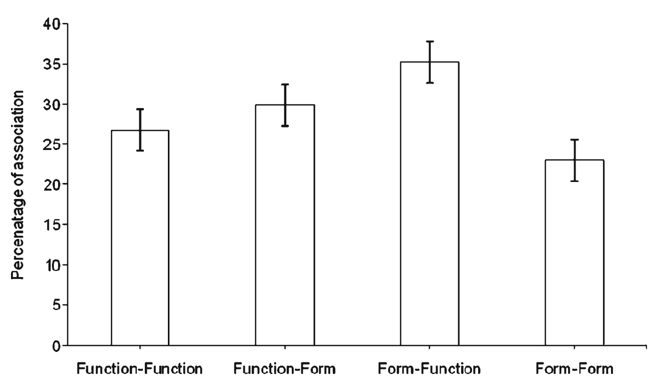

Fig. 1 Mean percentages of association (i.e., of "yes" responses) as a function of feature-type combination. Error bars represent standard errors of the means

features, the specific relation between form and function did not emerge as particularly salient. Instead, the statistical co-occurrence of features seemed to modulate the extent to which two features were considered correlated, regardless of feature type. To investigate whether these results were specific to the restricted set of features used in this experiment, or whether the conclusions might be generalized to other features and tasks, we carried out Experiment 2, employing a broader set of object features and another experimental task.

Experiment 2

Experiment 1 produced no strong evidence for the particular salience of form–function correlations relative to other correlations involving function features. However, the fact that only a small set of features was used might have diminished the roles of feature correlations and of the specific nature of the feature type. We tested this possibility in Experiment 2, in which the constraint of using a very specific set of features was reduced. In a feature generation paradigm, participants were presented with either a form or function feature from a larger and more diverse set, and they were asked to generate a second feature that they considered to be related to the first one.

Again from the results of Moss, Tyler, and colleagues (e.g., Tyler et al., 2000; see also De Renzi & Lucchelli, 1994), one might expect that participants would particularly generate a function feature if the first feature presented was a form property, or generate a form given a function feature. According to Caramazza et al. (1990), the effect would only be important in the former case (i.e., generation of a function feature when a form feature was presented). Alternatively, if the type of feature correlation was not critical, but instead the degree of association of the features plays a crucial role, then no superior generation of form–function (or function–form) feature pairs would be expected.

Method

Participants A group of 29 undergraduate students participated for partial fulfilment of an introductory psychology course requirement.

Materials A total of 40 features of tools and utensils were selected from those given in the McRae et al. (2005) and Garrard, Lambon Ralph, Hodges, and Patterson (2001) feature norms; half of the features corresponded to perceptual form features, and half to functional features (see the Appendix for the full list of features). The features were further divided into two blocks with equal numbers of form and functional features so that related features (e.g., "has a blade," "used for cutting") would not be presented to the same participants, to avoid possible contamination from previously having answered to a given feature. Ten other features were also included in the experiment as filler items, so that the nature of the features would not be so evident to the participants. Each block was composed of 30 features: 10 form features, 10 function features, and 10 other, diverse features. The trials in each block were presented randomly. All materials were mounted and presented using the Superlab for Windows software.

Procedure Participants were randomly selected for Block 1 or Block 2 and were tested individually following the same instructions. They were told that they would be presented with written sentences containing an object feature and that their task was to generate a second feature related to the one that was presented (e.g., for the feature "can be used to play music," they could say "has keys" or "is loud"). Participants were also warned that if they generated an associated concept (e.g., "piano") or repeated the presented feature in other words (e.g., "makes music"), their response would be considered incorrect. Nevertheless, they were told that a given feature (e.g., "has a keyhole") could be related to several other features (e.g., "can be used with a key," "has a slit"), and thus that more than one correct response was possible. Following a warning signal (an asterisk) that appeared for 500 ms, the first feature (e.g., "is sharp") was presented for 3,000 ms, and participants were instructed to read it silently. A question mark was then presented, and participants had 10,000 ms to verbally generate a second, related feature, which was separately recorded. After the answer was given, a blank screen appeared for 500 ms, and the next trial begun. Responses were given orally and were all recorded.

Results and discussion

The data from 2 participants with a large number of incorrect responses (more than 30%) were discarded, as they seemed to not properly understand the task ($n = 27$). Overall, the task was considered difficult, resulting in a total of 10% nonresponses and 6% incorrect responses [with no significant differences between feature types; $F(1, 38) = .27$, $MSE = 231.66$, n.s.]. Three judges independently coded all features generated using McRae et al.'s (2005) taxonomy (98% agreement; inconsistencies were resolved by final discussion between the judges). Features were classified as denoting a function feature (i.e., what an object is used for—e.g., for hanging or to make soup), a visual-form feature (i.e., an external component or part—e.g., is sharp, has teeth), another type of visual feature (e.g., colour, visual motion, or material—e.g., is white, is made of wood), a sensory feature (i.e., auditory, tactile—e.g., is noisy, is hard) or an encyclopedic feature (i.e., other, nonsensory or nonfunctional features—e.g., is electrical, must be handled carefully). For each form or function feature presented to the participants, the percentages of second features generated for each feature type were calculated, and the mean results are presented in Fig. 2.

As can be seen from Fig. 2, function features were the ones most produced, regardless of the type of first feature presented, and this was confirmed via statistical analysis. A 5 × 2 ANOVA showed a main effect of the feature generated, $F(4, 152) = 101.61$, $MSE = 144.88$, $p < .01$, with post hoc analysis (Tukey HSD test) showing that a larger percentage of function features was produced, relative to all other feature types. A significant interaction of the initial feature type with the feature type generated was also found, $F(4, 152) = 2.56$, $MSE = 144.88$, $p < .05$, such that the percentage of form features generated was larger when the initial feature was a function rather than a form feature (Tukey HSD test).

Overall, these results show the strong salience of function features, which overwhelms the saliences of both form–function and function–form correlations. Regardless of the initial feature presented, the large majority of participants generate a function feature. Moreover, the fact that form–form associations are less prevalent than function–form associations, as in Experiment 1, may explain why we feel that the latter have a particular status. These results were further explored in Experiment 3.

Experiment 3

Both Experiments 1 and 2 used slower, offline tasks that depended on consciously accessing information about feature co-occurrence and feature associations. We chose these tasks because previous studies had shown that the use of information regarding knowledge-based correlations was more important to performance on these tasks than on speeded online tasks (e.g., Ahn et al., 2002; Barrett et al., 1993; Malt & Smith, 1984; McNorgan et al., 2007). However, Experiment 1 also showed that judging the relation between features was modulated by their statistical correlation, a characteristic that impacts on speeded online task performance (see, e.g., McRae et al., 1997; Wattenmaker, 1991). In addition, more recent studies have demonstrated effects of statistical and knowledge-based correlations on both kinds of tasks (McNorgan et al., 2007). As such, one could argue that the reason that we did not find a particular salience for form–function correlations was that this kind of information is simply less consciously accessible, and thus more difficult to report explicitly. The fact that the feature correlations in Experiments 1 and 2 were prompted without reference to any particular object could also add to this difficulty in accessing feature correlations.

To test this possibility, we evaluated the roles of the same types of feature correlations (i.e., form–form, form–function, function–form, and function–function) using a priming paradigm and a lexical decision task, in which form and function features were used as primes and targets, and priming effects were assessed within and between feature types.

Following Moss, Tyler, and colleagues (e.g., Tyler et al., 2000; and also De Renzi & Lucchelli, 1994), one might expect that priming would be particularly strong when form–function and function–form features pairs are presented, while according to Caramazza et al. (1990), priming effects should only occur when the prime is a form feature and the target is a function feature. However, considering the results of the previous experiments and the previous

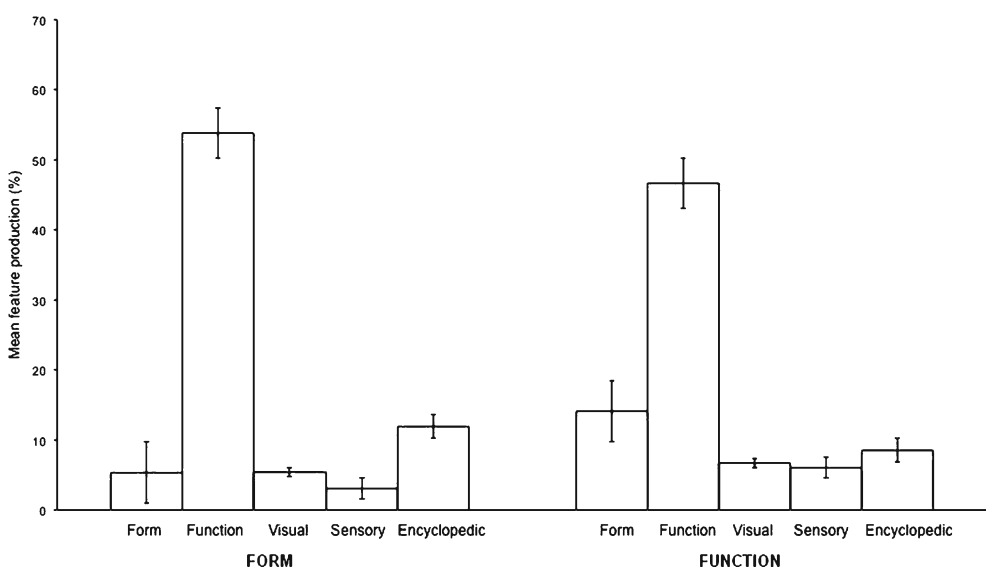

Fig. 2 Mean percentages of features produced, by feature type (form, function, visual, sensory, or encyclopedic), as a function of the initial feature type (form or function). Error bars represent standard errors of the means

findings on the impact of statistical correlations between features on speeded online tasks, two possible alternatives could further be considered. If function features are the most salient overall, as the results from Experiments 1 and 2 seem to suggest, priming should be stronger whenever the prime word is a function feature. Alternatively, if the type of feature correlation is not critical, but instead the degree of association of features plays a crucial role, then we would expect similar priming effects for all prime–target combinations, as the strength of the prime–target association would be controlled for within and between feature types.

Method

Participants A group of 20 undergraduate students participated for partial fulfilment of an introductory psychology course requirement.

Materials A total of 12 prime–target feature pairs were developed for each feature-type correlation condition (i.e., form–form, form–function, function–form, and function–function). Targets were matched in terms of numbers of letters and linguistic frequency for Portuguese (Nascimento, Casteleiro, Marques, Barreto, & Amaro, no date) across all conditions (all *F*s n.s.). In addition, 12 other, unrelated primes were chosen for each condition and matched to the related primes in terms of numbers of letters and linguistic frequency (all *F*s n.s.; see Table 1).

The degree of relatedness between prime and target was determined by means of scores in a pretest, in which 16 participants (who did not participate in the priming experiment), were asked to rate the degree of relatedness between the different word pairs (related and unrelated) using a 5-point scale. Each participant only rated half of the related and half of the unrelated pairs (counterbalanced between participants), so that each target was only rated once with a given prime. The results from the pretest (see Table 2) showed that the degree of judged prime–target relatedness only differed between related and unrelated pairs [$F(1, 48) = 346.20$, $MSE = 104.2$, $p < .01$], but not between the four feature-type conditions (see the Appendix for the full list of critical feature pairs).

The 48 targets were then divided into two blocks, so that in each block half of the targets in each condition were paired with a related prime and half were paired with an unrelated prime (with related and unrelated pairs counterbalanced between blocks). The full set of materials also included 24 unrelated word–word pairs and 72 word–pseudoword pairs (which were the same for the two blocks). All of the materials were mounted and presented using the E-Prime software.

Procedure The participants were randomly distributed to Block 1 or Block 2 and were tested individually following the same instructions. The participants were told that they would be presented with pairs of either two words or one word and one pseudoword and that their task would be to read all stimuli and decide in each case whether or not the second element of the pair was a real word. Following a warning signal (an asterisk) that appeared for 500 ms, the first prime word was presented for 250 ms, and participants were instructed to read it silently. After presentation of a blank screen for 50 ms, a second target word or pseudoword was presented for 2,000 ms, and participants had to decide whether or not it was a real word, by pressing a right key for "yes" and a left key for "no" (the reverse mapping was used for left-handed participants). After the answer was given, a second blank screen appeared for 500 ms before the presentation of the next trial.

Results and discussion

Overall, the mean correct response rate was 93% for the critical trials. Nevertheless, the data from 1 participant were eliminated due to a large number of incorrect responses and

Table 1 Mean numbers of letters and linguistic frequency by type of feature pair

	Targets	Pair Related	Pair Unrelated
Form–Form Pairs			
Number of letters	6.58	6.80	6.80
Ling. freq. (log)	2.19	2.31	2.30
Form–Function Pairs			
Number of letters	5.67	6.00	6.00
Ling. freq. (log)	1.76	1.81	1.80
Function–Form Pairs			
Number of letters	6.08	5.40	5.60
Ling. freq. (log)	2.70	2.24	2.20
Function–Function Pairs			
Number of letters	6.17	5.80	5.90
Ling. freq. (log)	1.62	1.78	1.80

Table 2 Mean ratings of prime–target relatedness by type of feature pair

	Pair Related	Pair Unrelated
Form–form pairs	3.23	1.42
Form–function pairs	3.69	1.64
Function–form pairs	3.59	1.49
Function–function pairs	3.83	1.47

below-chance performance for pseudowords (n = 19). Since item variability on critical variables was experimentally controlled for, we only report an analysis by subjects (Raaijmakers, Schrijnemakers, & Gremmen, 1999).

RTs were analyzed using a using a 2 × 2 × 2 repeated measures ANOVA, considering prime relatedness (related, unrelated), type of prime (form, function), and type of target (form, function), after trimming the data of incorrect answers and outliers, defined as trials two standard deviations above each participant's mean RT (corresponding to the elimination of 2% of the data, which is within the normal recommended limits; Ratcliff, 1993). The results are presented by condition in Table 3.

The results showed a significant Prime Relatedness × Type of Prime interaction, $F(1, 19) = 8.76$, $MSE = 39{,}233$, $p < .01$. Post hoc analysis (Tukey HSD test) showed that RTs were slower for unrelated than for related primes when the prime was a function feature, but not when the prime was a form feature. A priming effect was thus observed whenever the prime was a function feature, irrespective of the target presented, but not when the prime was a form feature. There were no other significant main or interaction effects.

These results are in accord with the overall salience of function features found in Experiments 1 and 2. Moreover, the use of a speeded online task argues against the interpretation that the results from Experiments 1 and 2 were due to the fact that information about form–function correlations is less consciously accessible, and thus more difficult to report explicitly. These results are further analyzed in the General Discussion.

General discussion

In the present study, we set out to evaluate the importance of and sensitivity to form–function (and function–form) correlations in healthy adults using real feature knowledge. Importantly, since we directly probed the feature relations of real tools and utensils and the tasks did not include specific objects, we were able to study the processing of real object features without the possible biases of testing specific objects (real or artificial). The salience of form–function knowledge-based correlations was compared with that of other types of feature correlations, notably form–form and function–function correlations.

Table 3 Mean response times (in milliseconds) by condition

	Form–Form	Form–Function	Function–Form	Function–Function
Unrelated prime	673	695	748	715
Related prime	678	694	670	669
Priming effect	–5	+1	+78	+46

The results from the first two experiments, using different explicit tasks and sets of features, showed that form–function correlations were more salient than form–form correlations, and Experiment 2 additionally showed that function–form correlations were also more salient than form–form correlations. These results suggest that functional information can be inferred from perceptual properties (Caramazza et al., 1990), and they also, though perhaps not so strongly, support claims that form–function correspondences are instantiated by links that support activation not only from form to function, but also in the reverse direction (e.g., De Renzi & Lucchelli, 1994; Tyler et al., 2000).

In addition, the statistical co-occurrence of features emerged as an important factor that influenced the degree of the judged association in Experiment 1, independently of feature type. This result is in line with the large body of evidence showing that people possess this statistical knowledge and that it impacts their behaviour (e.g., Chin-Parker & Ross, 2002; McRae et al., 1999; McRae et al., 1997; Wattenmaker, 1991, 1993). Moreover, along with other data (McNorgan et al., 2007), our results demonstrate that this implicit statistical knowledge may influence the use of our more explicit intuitive theories about correlations—namely, by making knowledge-based feature correlations more salient.

In both Experiments 1 and 2, the activation of form–function correlations was similar to the activation of function–function correlations. Thus, even though participants easily identified form–function correlations, these correlations were not particularly salient when directly compared with other feature correlations that involved function features. In agreement with these findings, Experiment 3 showed that when access to feature relations is tested in a more implicit manner, function features emerge as the most relevant, independently of the particular type of correlation.

It is important to note that while the theoretical justification for the salience of form–function correlations is vast and diverse, to date very little empirical support for this salience has been found, and the few findings have been based on studies using artificial concepts in which sensitivity to these correlations has not been evaluated in comparison to other feature-type correlations (Kemler Nelson et al., 2000; Lin & Murphy, 1997; Madole & Cohen, 1995; McCarrell & Callanan, 1995). The present results also offer an explanation as to why we may subjectively feel that form–function correlations are particularly salient: This may be related to the facts that form–form correlations are judged as low in association strength in comparison with form–function correlations (Exp. 1) and are less generated in comparison to function–form associations (Exp. 2). Moreover, this feeling may be exacerbated in situations in which only this type of correlation is explicitly presented to participants, such as in the case of artificial concepts (e.g., Kemler Nelson et al., 2000; Lin & Murphy, 1997). We suggest that when other types of feature correlations are equally available—either explicitly or implicitly, as in the present study—the salience of form–function relations is lost.

Taken together, the findings of these three experiments demonstrate the superiority of function information for tools and utensils. Function information is readily activated from either previous form or function features in explicit conditions (Exps. 1 and 2), and it also activates other conceptual knowledge (either form or function) in more implicit conditions (Exp. 3). This is in line with several behavioural studies demonstrating that function information (what an object is used for) is crucial for the representation of objects (e.g., Barton & Komatsu, 1989; Cree & McRae, 2003; Gelman, 1988; Keil, 1989; Warrington & Shallice, 1984). Neuroimaging studies have also demonstrated that function information can be activated even when it is not task relevant (Hoenig, Sim, Bochev, Herrnberger, & Kiefer, 2008), supporting the salience of functional information in object processing. The fact that a particular feature type (i.e., function) is salient to the representation of a particular class of objects (artefacts) is in agreement with a modality-specific account of conceptual knowledge, in which specific kinds of features (e.g., form, colour, or function) have differential importance for representing different concepts (e.g., Barsalou, 2008; Kiefer & Pulvermüller, in press; Marques, Canessa, Siri, Catricalà, & Cappa, 2008).

The finding that function–function correlations are as important as form–function correlations, both in more explicit and implicit tasks, is a novel result that merits further theoretical and empirical evaluation. While they support the overall importance of function to the representation of artefacts, the present results do not allow us to firmly conclude on the possible role of function–function correlations. One possibility is that all feature correlations are a by-product of the importance of function to artefacts. Another possibility is that many objects have more than one function, and as such, it is plausible that a given function feature points to other functions of the same object. What is the role of function relations? Can they be distinctive of particular objects having particular functions? These are empirical and theoretical questions that the present results raise.

The salience of function features may also be related to the use of a verbal task in the present experiments. Several studies have shown that in feature classification tasks, functional decisions are made faster than perceptual decisions (e.g., Marques, 2002; Thompson-Schill & Gabrieli, 1999). This finding reflects more rapid access to functional than to perceptual information when materials are presented verbally and may also be related to occasional difficulties in the use of verbal labels to describe other conceptual properties. Furthermore, function features are generally more associated with verbs and form features with nouns. As such, it would also be important to evaluate the extent to which the present results are dependent on stimulus format.

Additionally, while the present tasks were successful in probing feature relations without reference to any particular concept, the results from Experiments 1 and 2 also showed that these are hard tasks that may have led participants to be more conservative in their judgements. However, Experiment 3 argues against an interpretation of the results exclusively on the basis of task difficulty, as feature correlations involving function were clearly more salient when these correlations were assessed implicitly. Nevertheless, it is conceivable that participants solved the tasks by activating particular object concepts in which the features probed occurred. As such, the relative importance of different feature correlations should also be assessed when features are directly associated with specific concepts.

In the present study, the function of an object is understood as the intended use or utility of an object. However, an important question from past debates has regarded the extent to which function features are a homogeneous feature type and how they are related to more concisely defined conceptual features, such as action features that refer to object manipulability (Kellenbach, Brett, & Patterson, 2003). More recently, function has been proposed as an emergent and multidimensional property of objects (e.g., Chaigneau, Barsalou, & Sloman, 2004; Oakes & Madole, 2008). Under this perspective, different pieces of knowledge about an object's use, the actors' intentions, the physical limitations of an object's use, and the sequence of events when using an object are joined together in a causal model that determines one's "functional sense" about a particular object (Oakes & Madole, 2008). Given the prominent status of functional features in the conceptual structure of artefacts, it will be important in future studies to consider other aspects of functions, beyond the intended use.

In conclusion, the present research helps to elucidate the status of form–function correlations in the representation of tools and utensils. People seem able to identify form–function correlations and may feel that they have a salient position in the structure of these concepts. However, in light of the present results, we propose that this salience is a by-product of the crucial, and more general, role that function information plays in accessing the representations of object concepts.

Appendix

Table 4 List of form and function features used in Experiment 2 (English equivalents)

Form Features	Function Features	Other
has a blade	used for erasing	is an appliance
has a concave end/ladle	used for tightening bolts	is dangerous
has a flat head	used for stapling	is electrical
has a graphite point	used for gripping	is heavy
has a hand grip	used for carrying things	is made of metal
has a handle	used for digging	is noisy
has a hole	used for cutting	is used with both hands
has a knob	used for threading	sold in hardware stores
has a metal spiral	used for writing	used in the kitchen
has a pointed end	used for making holes	used on the beach
has a spring	used for drilling	
has an eraser on end	used for smoothing	
has bits	used for cleaning	
has bristles	used for measuring	
has sharp teeth	used for breaking things	
has two blades	used for opening	
has two handles	used for grasping	
is long	used for pounding	
is sharp	used for removing corks	
is triangular	used for sawing	

Table 5 List of critical feature pairs used in Experiment 3 (English equivalents/Portuguese originals)

	Target	Related Prime	Unrelated Prime
Form–Form	thin/fino	long/comprido	illegal/ilegal
	narrow/estreito	round/redondo	modern/moderno
	legs/pernas	tabletop/tampo	green/verde
	curved/curvo	oval/oval	isolates/isola
	smooth/liso	straight/direito	energetic/enérgico
	pleats/pregas	wrinkled /enrugado	sticky/pegajoso
	cubic/cúbico	square/quadrado	soft/mole
	pyramidal/ piramidal	triangular / triangular	decorative/ decorativo
	circular/circular	spherical/esférico	manual/manual
	rectangle/ rectângulo	flat/plano	tired/cansa
	flattened/ achatado	short/curto	bright/luminoso
	wide/largo	thick/grosso	common/vulgar
Form–Function	grinds/tritura	blade/lâmina	addicted/viciado
	drills/fura	drill/broca	refuses/recusa
	cuts/corta	serrated/dentado	lies down/deita
	grabbed/agarrado	handle/cabo	facial/facial
	bounces/salta	spring/mola	listen/ouvem
	stings/pica	pointed/ ponteagudo	ties/ata
	stores/armazena	deep/fundo	quiet/tranquilo
	rips/rasga	sharp/afiado	limits/limita
	slides/desliza	slope/inclinado	edible/comestível
	protects/protege	cover/tampa	ugly/feio
	files/lima	rough/rugoso	exotic/exótico
	steps/pisa	pedal/pedal	freezes/gela
Function–Form	point/bico	writes/escreve	prohibits/proíbe
	knob/maçaneta	opens/abre	supposes/supõe
	teeth/dentes	combs/penteia	profits/lucra
	handle/pega	grabs/agarra	frozen/gelado
	back/costas	sits/senta	mimics/imita
	concave/côncavo	contains/contém	fast/rápido
	wings/asas	flies/voa	licks/lambe
	lens/lente	magnifies/amplia	pulls/puxa
	cylindrical/ cílindrico	rolls/rola	innocuous/inócuo
	sharp/aguçado	breaks/rompe	expensive/caro
	long/longo	reaches/alcança	checks/confere
	fringe/franjas	sweeps/varre	mechanical/ mecânico
Function–Function	wipes/enxuga	washes/lava	delegates/delega
	rubs/esfrega	cleans/limpa	saves/poupa
	buries/enterra	digs/cava	shakes/sacode
	rises/levanta	hangs/pendura	gothic/gótico
	bakes/coze	heats/aquece	ignores/ignora
	shoots/dispara	injures/fere	valuable/valioso
	turns/gira	twists/torce	odd/ímpar
	films/filma	photographs/ fotografa	adopts/adopta
	burns/queima	lights up/ilumina	considers/pondera
	shrinks/encolhe	presses/aperta	guides/orienta
	wets/molha	drains/escorre	inserts/insere
	screws/aparafusa	holds/prende	smokes/fuma

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