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Qualitative differences in the representation of abstract versus concrete words: Evidence from the visual-world paradigm

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Abstract

In the present visual-world experiment, participants were presented with visual displays that included a target item that was a semantic associate of an abstract or a concrete word. This manipulation allowed us to test a basic prediction derived from the Qualitatively Different Representational framework that supports the view of different organizational principles for concrete and abstract words in semantic memory. Our results confirm the assumption of a primary organizational principle based on association for abstract words, different from the semantic similarity principle proposed for concrete words, and provide the first piece of evidence in support of this view obtained from healthy participants. The results shed light on the representational structure of abstract and concrete concepts.

Qualitative differences in the representation of abstract versus concrete words: Evidence from the visual-world paradigm

The representation and processing of concrete versus abstract words has important implications for memory and language theories. Research has shown an advantage for the processing of concrete words (e.g., *cross*) as compared to abstract words (e.g., *faith*), referred to as the *concreteness effect*. Compared to abstract words, concrete words show a recognition benefit in behavioural tasks and eye-movement studies (e.g., Bleasdale, 1987; James, 1975; Juhasz & Rayner, 2003), in electrophysiological correlates (e.g., Kounios & Holcomb, 1994), and in brain activation (e.g., Binder et al., 2005).

There have been different proposals to account for this processing advantage of concrete words. Most frameworks assume a *quantitative* difference, based on the amount of information available when processing abstract or concrete words. For example, it has been proposed that abstract words lack the sensory referents of concrete words (e.g., Paivio, 1986), or that concrete words benefit from the greater availability of related contextual information (e.g., Schwanenflugel & Shoben, 1983). Furthermore, some authors claim that concrete words are supported by a higher number of semantic features (e.g., Plaut & Shallice, 1991, 1993). However, a *qualitative* difference in the organization of concrete and abstract words in the mental lexicon has recently been proposed (e.g., Crutch, 2006; Crutch & Warrington, 2005; Crutch, Ridha & Warrington, 2006; Warrington & Crutch, 2007). In this view, concrete words are primarily organized following a semantic similarity principle, whereas abstract words are mainly organized by their association with other words. According to this view, the primary organizational principle for concrete words is categorical but not associative. In contrast, the representation of abstract words is assumed to rely primarily on semantic association rather than similarity.

This claim has received empirical support from patients with stroke aphasia who show a semantic interference effect (see Crutch & Warrington, 2005). In short, patients showed greater interference for abstract words embedded in an array of words organized by association (e.g., *theft* in an array that included *punishment*) as compared to an array created by categorical or synonymic relationships (i.e., semantic similarity; e.g., *theft* in an array that included *burglary*). The reverse pattern, however, was found for concrete words: concrete words showed greater interference in arrays defined by semantic similarity than in arrays defined by association.

The *qualitatively different representational* framework (QDR, for short) assumes that "*abstract concepts are represented in an associative neural network whereas concrete concepts have a categorical organization*" (Crutch & Warrington, 2005, p.623). Put differently, abstract words are assumed to be organized mainly by semantic association and concrete words mainly by semantic similarity[1]. Hence, the theory predicts that, once activated, an abstract word would predominantly co-activate associated concepts, whereas a concrete word would predominantly co-activate semantically similar concepts. Accordingly, abstract words are expected to activate their associates faster than concrete words, since this is their primary organizational

[1] Although the QDR framework seems to favour the existence of two separated semantic networks (an associative and a semantic similarity network), it is also possible that the differences proposed by the QDR for abstract and concrete concepts rely on different connection strengths between the representations in a single integrated multi-dimensional semantic network. In any case, predictions of the QDR for the processing of concrete and abstract word concepts do not strictly depend on whether these are organized in an integrated multi-dimensional network or in separate semantic networks. Further discussion of this matter would therefore go beyond the scope of the present investigations.

principle. The present experiment tested this hypothesis using the visual-world paradigm on healthy participants. This study is particularly relevant for two main reasons. First, the confirmation of such an effect within the population of healthy perceivers is important for generalization purposes. Previous evidence has only been obtained from patients suffering from semantic impairments. Considering that the QDR hypothesis is assumed to hold for intact semantic networks as well, a demonstration of its validity in healthy participants would be a vital addition to existing evidence in support of the theory. Second, the QDR framework predicts that differential association effects between abstract and concrete words should appear during on-line word recognition, which requires a paradigm capable of detecting such differences in real time. The visual-world paradigm is well suited for these purposes.

In this paradigm, an auditory sentence is presented together with a visual scene in which different entities are depicted, while the eye movements of the participant are tracked (e.g., Cooper, 1974, Tanenhaus et al., 1995). The eye movement patterns are affected by some of the properties of the linguistic input. Typically, a critical word in the sentence is related to one of the depicted elements and the proportion of looks to this item provides an index of the strength of the link between the picture and the related auditory input. The variety of relationships manipulated between the auditory input and the depicted items can range from form to syntactic or semantic levels (e.g., Allopenna, Magnuson, & Tanenhaus 1998; Dahan, Magnuson, & Tanenhaus, 2001; Huettig & Altmann, 2005; Kamide, Altmann & Haywood, 2003; Kamide, Scheepers & Altmann, 2003).

In the present study, we will focus on the semantic competition effects shown by Huettig and Altmann (2005). In their experiment, participants were presented with auditory sentences including a critical word (e.g. *piano*) while looking at a visual display comprising various objects in different quadrants. Interestingly, one of the depicted objects referred to a semantic competitor of the spoken word (*trumpet*). Participants fixated this object more than any of the other objects, which were unrelated distractors. The authors concluded that "*hearing 'piano' activated semantic information which overlapped with the semantic information encoded within the mental representation of the concurrent trumpet*" (p. B30). In other words, semantically related visual items become active when recognizing a word, and thus capture participants' visual attention. For this to be possible, visual attention must be guided by the link between specific properties of the visual input and the (auditory) linguistic input, as stated in the so-called *linking hypothesis* (Tanenhaus, Magnuson, Dahan & Chambers, 2000). Recently, Altmann and Kamide (2007) developed this proposal further to provide a more detailed account of the dynamics of eye movements in a visual-world experiment. Their *conceptual overlap linking hypothesis* assumes that the eyes move rapidly towards visual objects whose conceptual representations overlap with those of the objects named in the unfolding linguistic input (see also Dahan & Tanenhaus, 2005; Huettig & Altmann, 2004). In visual-world experiments, the visual input is typically available before the onset of a critical spoken word. Participants' pre-inspection of the visual scene leads to a pre-activation of conceptual (presumably feature-based) representations of the depicted objects, thereby leaving conceptually enriched episodic traces associated with different object locations in the perceptual experience. Next, with the unfolding of the critical part of speech, these pre-activated representations make contact with the conceptual representations activated by the linguistic input itself – the linguistic input effectively *re-activates* semantically related episodic traces. Altmann and Kamide (2007) proposed that this leads to a shift in visual attention such that perceivers are more prone to make a saccadic eye-movement towards the location of an object that is semantically related to the spoken input. Consequently, the greater the conceptual overlap between a visually presented object and a critical word in the sound stream, the greater the probability of a saccade "back to" the visual object. Huettig, Quinlan, McDonald and Altmannn (2006) provided support for the *conceptual overlap linking hypothesis*, by showing that semantic proximities in a multi-dimensional space of conceptual representations of visual and auditory stimuli (as derived from *Latent Semantic Analysis* or contextual similarity measures) are indeed a reliable predictor of eye movements in a visual-world experiment. In this sense, conceptual proximity effects obtained in visual-world experiments can be understood as an analogue to semantic/associative priming effects obtained in word recognition tasks (e.g., *doctor* activates *nurse* more than *butter*).

In the present visual-world experiment, Spanish participants were presented with spoken sentences containing a critical word that could be either concrete or abstract, and with concrete visual scenes that included a critical target object, together with three distractors. In the conditions of primary interest, the critical spoken words were semantic associates of the visual target (e.g., hearing *priest* and seeing a *cross*; hearing *happiness* and seeing a *smile*). Using the *conceptual overlap linking hypothesis* (Altmann & Kamide, 2007) and the different organizational principles proposed by the QDR framework (Crutch & Warrington, 2005) as a theoretical basis of our investigations, we aimed at exploring how mental representations activated by concrete versus abstract words link with conceptual representations of associated visual target objects over time. If abstract words are indeed more strongly linked to their relevant associates than concrete words, we should expect more looks towards the associated pictures when hearing an abstract word than when hearing a concrete word. In other words, when hearing an abstract word the spread of activation would primarily flow to associatively related concepts, whereas activation would primarily be spread to semantically similar concepts in the case of hearing a concrete word. Moreover, the visual-world paradigm will enable us to trace the time course of abstract versus concrete word processing.

Method

Participants. Thirty native Spanish speakers from the University of La Laguna took part in the experiment in exchange for 5 €.

Materials. Two sets of 39 displays were created. Each of these comprised four black and white drawings of objects such that each object occupied a distinct quadrant. There were always one target object and three distractor objects per display. The location of the target object varied across items. For the two sets of displays (i.e., concrete versus abstract), three types of sentences were created depending on the relationship between the critical word and the target object (see Figure 1): *associated*, *identical* or *unrelated*. The critical condition was the *associated* condition. For sentences in this condition, the critical spoken word was a strong associate of the depicted target item. For example, in the concrete set, the word *cuna* (‘crib’) was strongly associated with (the picture of a) BABY; in the abstract set, the word *olor* (translated as ‘the smell’) was strongly associated with (the picture of a) NOSE. The associative strength between the critical words and the depicted target objects was 26% for the abstract set and 28% for the concrete set, according to the Spanish free-association norms (Fernández, Díez, Alonso, & Beato, 2004). The other two conditions (*identity* and *unrelated*) were included for control purposes. For sentences in the *identity* condition, the critical word directly referred to the depicted target object (e.g., for the concrete set: *bebé*, 'baby'; for the abstract set: *nariz*, 'nose'). An *unrelated* condition was also included, where the critical word in the sentence had no relationship with the target object whatsoever (e.g., concrete set: *pila*, 'battery'; abstract set: *rato*, 'a while'). We expected no abstract/concrete differences to emerge in the *identity* and *unrelated* conditions.[2] Between the two sets of items (abstract versus concrete), critical words were equated for word frequency, number of syllables, phonemes, letters and neighbors (*t*-tests on these measures revealed no significant differences). Critically, the spoken words in the associative condition differed in concreteness ($p < .001$): words in the concrete set were rated as highly concrete (6 out of 7 in a concreteness norming study), and words in the abstract set were rated as more abstract (3.9 out of 7)[3]. A summary of the stimuli features is provided in Table 1 and the Appendix provides a full list of materials. The critical spoken words for the two sets were nouns in almost all cases (only two words in the abstract set and one word in the concrete set were verbs). All the sentences in this experiment started with exactly the same command (*Señala el dibujo correspondiente a…* [Point to the picture that corresponds to…]) and ended in the critical word. The onset of the critical word was kept constant at 2500 ms post sentence-onset via cross-splicing.

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[2] If any such abstract/concrete differences were to be seen in the eye-movement data from the *identity* or *unrelated* conditions, then these might reflect differences in the visual saliency or recognisability of the target object.

[3] Imageability scores for these conditions differed as well ($p < .001$). This is hardly surprising, given that concreteness is highly correlated with imageability (e.g., Cortese & Fugett, 2004; Toglia & Battig, 1978). For the abstract or concrete *identity* conditions, concreteness and imageability scores were expected to be high because the critical word in this condition always referred to a depicted object.

Figure 1

Example displays from the abstract (left hand panel) and concrete (right hand panel) item sets. The target object (*nose* and *baby*, respectively) is located in the superior left quadrant, while the remaining objects are distractors. Target and distractor locations varied across items so as to avoid any spatial expectations.

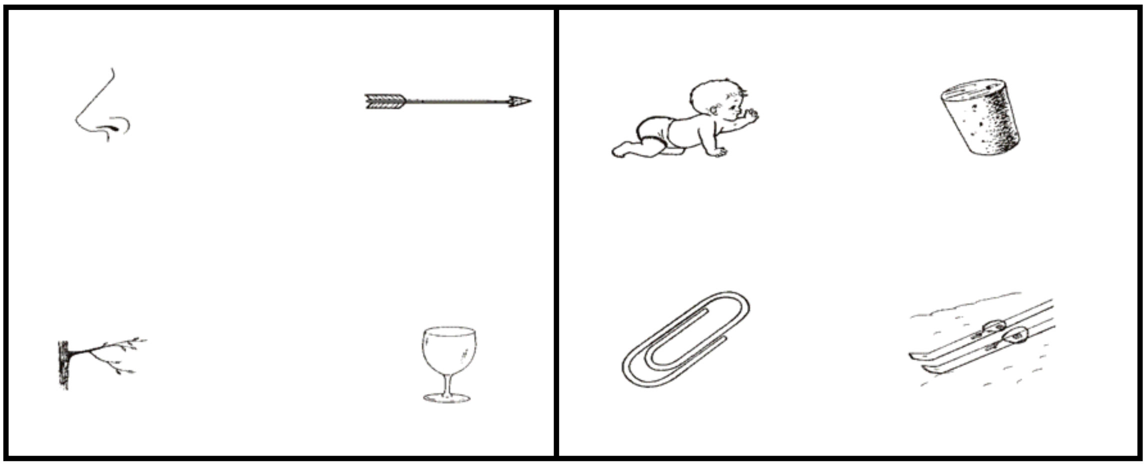


Table 1

Mean word frequency, number of syllables, number of phonemes, number of letters, number of neighbors, concreteness and imageability ratings for the spoken words used in the experiment.

	Frequency	Length	Phonemes	Syllables	Neighbors	Imageability	Concreteness
Concrete							
Identity	62.1	6.1	5.8	2.5	3.3	6.3	6.0
Association	23.1	6.2	6.0	2.6	2.6	5.9	**6.0**
Unrelated	23.0	6.2	5.9	2.7	2.5	5.6	5.8
Abstract							
Identity	83.6	5.6	5.4	2.4	3.8	6.1	5.9
Association	32.3	6.8	6.7	3.1	2.6	4.7	**3.9**
Unrelated	32.7	6.8	6.8	3.1	2.3	4.3	4.0

Importantly, we also ensured that there were no differences in semantic similarity between abstract words (e.g. *olor*, 'the smell') and their target associates (e.g. *nariz*, '*nose*') on the one hand and concrete words (e.g. *cuna*, 'crib') and their target associates (e.g. *bebé*, '*baby*') on the other. This was done on a variety of semantic similarity measures. First, we compared the two sets of word-associate pairs using *Latent Semantic Analysis* (LSA) in Spanish as well as LSA and HAL (*Hyperspace Analogue to Language*) in English (based on English translation equivalents of our materials)[4] which yielded mean similarity scores of 0.27 vs. 0.28, of 0.41 vs. 0.45, and of 1.51 vs. 1.44 for the abstract vs. concrete word-associate pairs, respectively. None of these comparisons yielded a significant difference (all *p*s > .37). In addition, we conducted a rating study in Spanish to confirm that the two sets of word-associate pairs were indeed comparable in terms of semantic similarity. To this end, 50 native Spanish participants completed an internet-based questionnaire in which all of the critical word-associate pairs (and a large

[4] Spanish LSA values were taken from http://www.elsemantico.com; English LSA values were obtained from http://lsa.colorado.edu/; English HAL values were taken from the HAL website http://hal.ucr.edu/. For LSA, see Landauer, Foltz and Laham (1998); for HAL, see Lund and Burgess (1996).

set of filler pairs) were presented in random succession. Participants were asked to rate each pair on a scale from 1 ("*the two concepts have nothing in common*") to 7 ("*the two concepts have a lot in common*"). Word-associate pairs in the abstract set achieved a mean similarity score of 5.46 (± 0.3 SD), and word-associate pairs in the concrete set a score of 5.53 (± 0.4 SD). As with the previous semantic similarity norms, this difference was not significant ($p > .35$). Across items, correlations between the different semantic similarity measures (Spanish LSA, English translation LSA, English translation HAL, and Spanish similarity ratings) were significant (all *p*s < .01), suggesting that they measured the same construct (semantic similarity) in a reasonably consistent manner. Overall, it is therefore safe to conclude that concreteness (or imageability) of the critical word was the only variable in which our abstract vs. concrete sets of items differed.

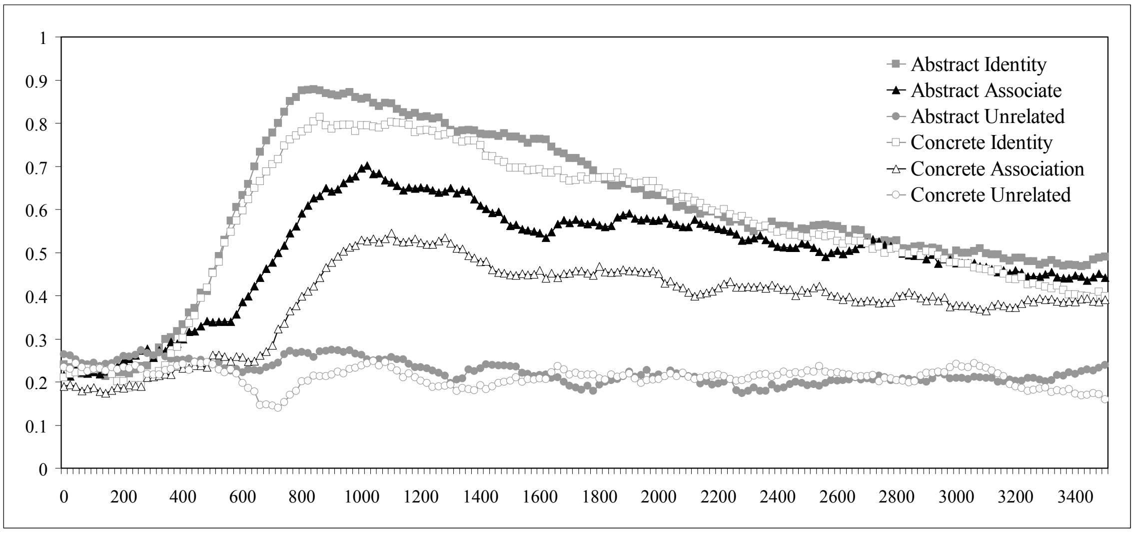
Apparatus and Procedure. Participants' eye movements were recorded at a rate of 500 Hz using an SR Research EyeLink II head-mounted eye-tracker connected to a 21-inch color CRT for visual stimulus presentation. Procedures were implemented in SR Research Experiment Builder. Only data from the right eye were analyzed. Calibration and validation processes were carried out at the beginning of the experiment and repeated several times per session. Each trial started with the presentation of a central fixation dot for drift correction, followed by the presentation of the target display. After a 1000 ms preview period, the spoken sentence was presented via headphones. Each display remained on the screen for 7000 ms. Participants were instructed to listen to the sentences carefully and were told that in some trials the critical word in the auditory sentence would match one of the items displayed, in which case they had to press a button corresponding to the location of that item in the scene (note that this only occurred for items in the *identity* condition, accounting for 33% of the trials). This way, we ensured that participants explored the visually presented objects and tried to find a correspondence with the linguistic input in all the trials, which was essential for the purposes of the experiment.

Results

Descriptive data. Bitmap templates were created for each of the experimental displays which identified the three distractor objects, the target object and the background in each display. The object regions were defined in terms of rectangles containing the relevant objects; fixations landing within the perimeters of these rectangles were coded as fixations on the relevant objects. The output of the eye-tracker included the *x*- and *y*-coordinates of participants' fixations, which were converted into region codes using the templates. Fixations shorter than 80 ms were pooled with preceding or following fixations if within 0.5 degrees of visual angle. Times for blinks were added to the immediately preceding fixations. The time period between the onset of the critical word in the sentence (2500 ms) and the end of the trial (7000 ms) was divided into 20 ms time slots. For each time slot, the number of fixations on the target object was counted and converted into fixation probabilities (Figure 2). As can be seen, the abstract versus concrete *identity* conditions did not differ from one another in the number of looks to the target over time, and this was also the case for the two *unrelated* conditions. By contrast, clear differences arose between the abstract versus concrete *associate* conditions, on which we will focus our inferential analyses below.

Figure 2

Probabilities of fixations on the target object in the identity, associated and unrelated conditions for the concrete and abstract sets of items. Time is plotted on the x-axis (in 20 ms resolution) starting at the onset of the critical word and ending 3.5 seconds later.



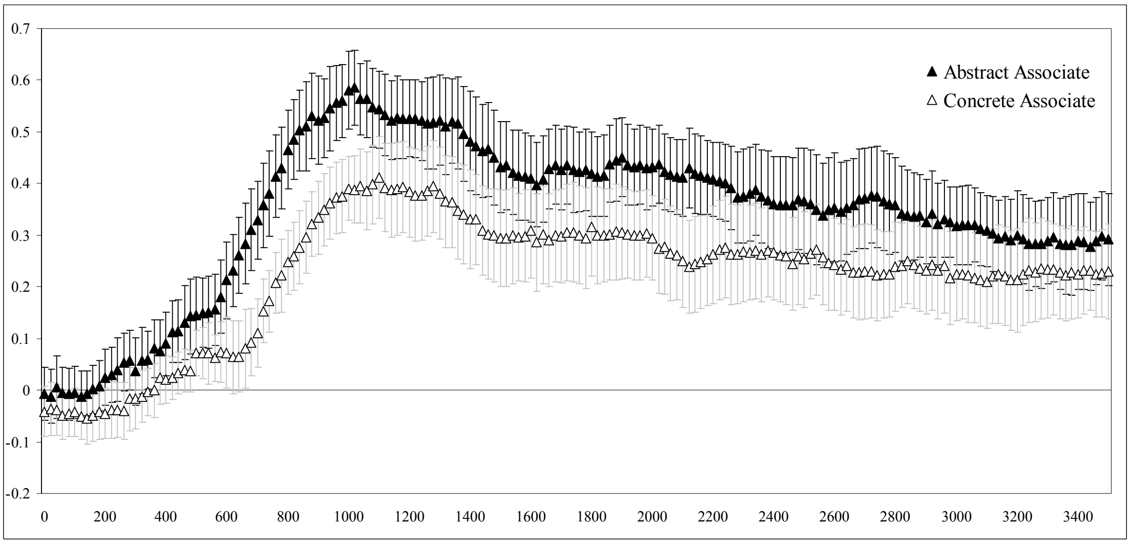
A pre-inspection of fixation probabilities on the distractor objects in the relevant trials indicated no differences over time (*p*s > .2 by log-linear analyses). That is, each distractor was about equally likely to be fixated in each time slot, and this was regardless of sentence condition (again, *p*s > .2).[5] This was expected, as the distractor objects had no obvious relationship with any of the critical words. We therefore calculated a common *baseline* for each time slot by simply averaging fixation probabilities across the three distractor objects and the two sentence conditions. Next, we subtracted this baseline from the *associate* probability curves (Figure 2) such that positive values indicate a visual preference for the target object over any of the distractors. The resulting data are shown in Figure 3, together with 95% confidence intervals by subjects. As can be seen, in the *abstract associate* condition (critical word:

[5] Given that the baseline (probability of fixating any of the distractors) was constant across conditions, it appears that cross-condition differences in looks to the target were complemented with increasing/decreasing looks to the background.

olor, 'the smell'), fixation proportions on the target object (nose) started to significantly rise above baseline at around 360 ms post critical-word onset; in the *concrete associate* condition (critical word: *cuna*, 'crib'; target object: baby), this deviation from baseline was delayed until about 660 ms after the critical word onset**.** Moreover, in the time interval of 620–1100 ms, the proportion of looks to the target was clearly higher in the *abstract* than the *concrete associate* condition.

Figure 3

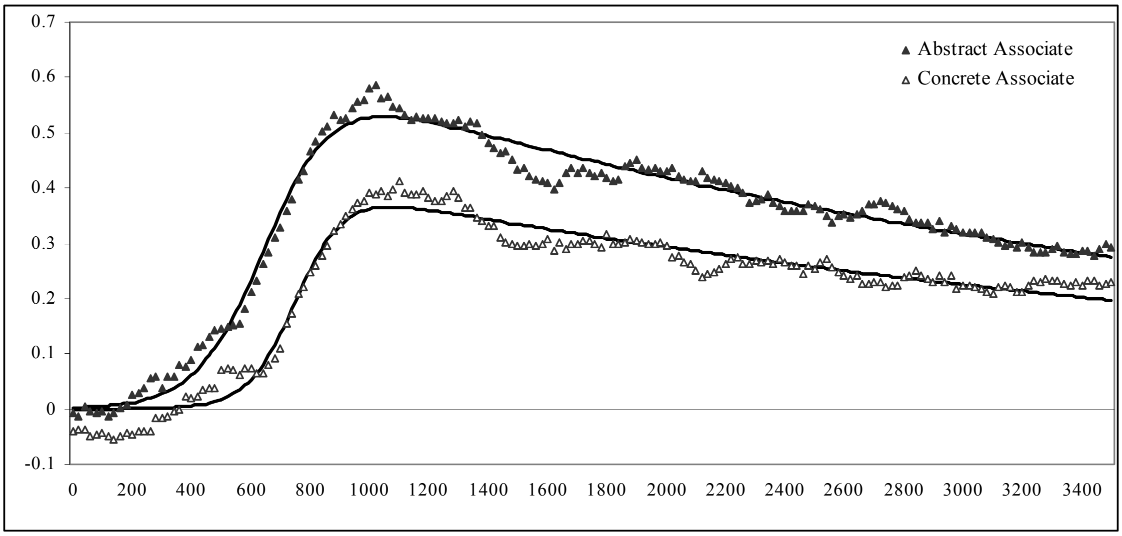
Probabilities of fixating the target object in the abstract and concrete associate conditions relative to the probability of fixating any of the distractor objects (baseline), measured in 20 ms resolution over a time period of 0-3500 ms after word onset. Positive values indicate a visual preference for the target object over any of the distractor objects. Error bars represent 95% confidence intervals by subjects such that no overlap between conditions indicates a significant difference.



Time course analysis. In order to examine the time course of the association effect for concrete and abstract words in more detail, we followed the analysis technique described in Scheepers, Keller, and Lapata (2008) by fitting a *Logistic Power Peak (LPP)* function to each of the curves in Figure 3. The *LPP* function comprises four parameters that describe different characteristics of the gaze probability distributions over time: the amplitude (λ) and temporal location (δ) of the peak, the width of the distribution (β), and a symmetry parameter (γ) which alters the rate of decline from the peak in the right tail of the distribution (see Scheepers et al., 2008, for a detailed description).

Figure 4

Data from Figure 3 modeled in terms of a four-parameter Logistic Power Peak (*LPP*) function fitted to either of the critical conditions (filled symbols: observed *abstract associate* data; unfilled symbols: observed *concrete associate* data). Solid lines indicate the *LPP* fits.



We fitted this function not only to the grand average data in Figure 3 (cf. Figure 4), but also to subsets of data, enabling us to evaluate the statistical consistency of the model fits. As it was not feasible to fit *LPP* curves to each individual data set (reasonably stable parameter estimates require large numbers of trials per condition), we randomly aggregated the 30 subject data sets into five "super-subject" data sets, each comprising data from six participants. This was done twice (Draw 1 and Draw 2, each time creating a different random grouping of the original participant data sets) for cross-validation purposes. The *LPP* function was then applied to each of the resulting 10 super-subject data sets using TableCurve 2D. Table 2 shows the resulting parameter estimates and goodness-of-fit statistics (R^2) in each of the critical two conditions (*abstract* versus *concrete associate*).

Cross-condition comparisons of the parameter estimates (λ, δ, β, and γ) were based on two-tailed Wilcoxon Signed-Ranks Tests[6], performed separately for each draw. These tests confirmed consistently higher target-bias amplitudes (λ) in the *abstract* rather than *concrete* associate condition: $p < .05$ for both Draw 1 and Draw 2. The remaining parameters did not reliably differ between conditions, except for a marginal difference in width (β): $p = .08$ for Draw 1; $p < .05$ for Draw 2. We also considered a composite measure (see *Area* figures in Table 2) defined as the area under the curve between 0 and 1000 ms after critical word onset in proportion to the estimated amplitude, i.e. ${}_0\int^{1\mathrm{sec}}/\lambda$ (the relevant integrals were determined on the basis of the *LPP* fits using the Gaussian Quadrature procedure). Wilcoxon Signed-Ranks Tests on this measure established a significant cross-condition difference ($p < .05$ for both Draw 1 and Draw 2), meaning that within one second from critical word onset (i.e. shortly before reaching the peak on average), subjects have accumulated a significantly higher proportion of the maximum visual bias towards the target object when the critical word is *abstract* rather than *concrete* (see also Figure 5). This corroborates our observation from the 95% CIs in Figure 3, namely that the visual bias towards the target object develops earlier in the abstract rather than concrete associate condition, even when differences in amplitude are neutralised.

[6] This test does not rely on normality and is suitable for small Ns.

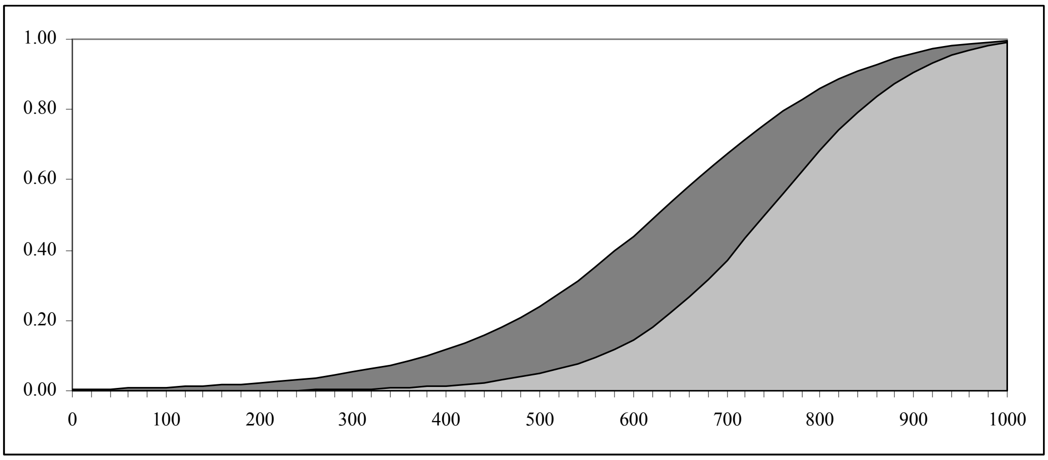
Table 2

Mean *LPP* parameter estimates per condition, separately for each 'super-subject' and for the average fit in Figure 4. *Area* refers to the amplitude-normalised area under the curve (in probability × time units) between 0 and 1000 ms after word onset ($_0\int^{1sec}/\lambda$). R^2 refers to the proportion of variance accounted for by the *LPP* function in each data set and condition.

	Super-subjects from Draw 1					Super-subjects from Draw 2					
	1A	1B	1C	1D	1E	2A	2B	2C	2D	2E	Average Fit
Abstract Associate											
λ	**0.36**	**0.58**	**0.58**	**0.60**	**0.62**	**0.62**	**0.63**	**0.59**	**0.52**	**0.55**	**0.53**
δ	932	1262	1239	1107	960	1098	967	1373	1123	1222	1069.30
β	75.58	163.47	158.57	146.28	68.59	90.41	106.57	187.25	128.21	197.78	115.54
γ	51.36	33.45	30.95	16.86	42.57	53.66	23.82	28.34	26.67	7.74	30.99
Area	**383.96**	**368.41**	**362.11**	**378.97**	**316.14**	**284.15**	**413.51**	**331.61**	**347.18**	**337.91**	**367.79**
R^2	0.71	0.86	0.93	0.93	0.96	0.95	0.92	0.97	0.88	0.94	0.98
Concrete Associate											
λ	**0.32**	**0.43**	**0.32**	**0.35**	**0.47**	**0.42**	**0.41**	**0.27**	**0.44**	**0.34**	**0.37**
δ	1063	1174	1169	1165	1053	1026	1111	932	1251	973	1092.92
β	66.58	78.41	105.73	69.24	71.82	44.14	99.58	37.51	115.15	30.09	83.01
γ	39.38	61.52	33.77	333.73	35.19	453.35	37.71	237.07	16.47	75.39	45.58
Area	**201.03**	**170.89**	**241.30**	**242.56**	**225.56**	**245.73**	**281.22**	**276.05**	**147.72**	**162.12**	**247.58**
R^2	0.89	0.89	0.84	0.90	0.95	0.93	0.90	0.82	0.91	0.84	0.96

Figure 5

Amplitude-normalised areas under the curve between 0 and 1000 ms after critical word onset for the *abstract associate* condition (dark grey) and the *concrete associate* condition (light grey), derived from the LPP fits in Figure 4. As a result of amplitude-normalisation, both conditions achieve a maximum of 1.



Discussion

The QDR framework (e.g., Crutch & Warrington, 2005; Crutch, Ridha & Warrington, 2006; Warrington & Crutch, 2007) states that the main difference between abstract and concrete words is the way in which they are represented in semantic memory: abstract words are primarily organized following an association principle, whereas concrete words are primarily organized by a semantic similarity principle. Indeed, Crutch and Warrington (2005, p.615) proposed that "*abstract concepts, but not concrete concepts, are represented in an associative neural network*". The present visual-world study supports this assumption by showing that participants tended to fixate more (and earlier) on depicted objects that were associates of abstract words than associates of concrete words. The results further suggest that this effect is unlikely to be due to the characteristics of the depicted target objects: no reliable abstract/concrete differences were found with unrelated words or words that directly referred to those objects (identity condition).

Until now, support for the QDR framework exclusively stems from studies of patients with deficits in semantic processing. In the present experiment, we tested healthy adults, due to the importance of demonstrating whether previous results could generalize to the normal population. It could be the case that healthy participants do not show the same pattern of results as patients with semantic processing deficits (see, for instance, differences in semantic processing for normal adults as compared to patients with Alzheimer; e.g., Hodges, Salmon, & Butters, 1992).

We have shown that, on hearing an abstract word, healthy participants' attention is quickly drawn to a target picture representing an associate of that word. Importantly, this is also the case for concrete words but to a lesser extent, and not as quickly as for abstract words. Hence, we not only found important differences in the overall likelihood of launching an eye movement to the associated target, but also in the time course of such an eye movement when hearing an abstract rather than a concrete word. The former difference became manifest in a peak amplitude (λ) difference, indicating that a fixation was generally more likely to occur on the associated target object when the critical word was abstract rather than concrete. The difference in time course was evidenced by the fact that the visual bias towards the target object developed earlier in the abstract than in the concrete associate condition even when differences in peak amplitude were neutralised (cf. Figure 5). The most straightforward interpretation of these results is that abstract and concrete words differ in the way they are represented in semantic memory: associated concepts are more readily available for abstract than for concrete words. Thus, the present study represents the first empirical evidence obtained with healthy subjects supporting the QDR approach, as the results reveal differences in abstract versus concrete word processing in both the strength and the time course of association effects, and importantly, even when factors such as semantic similarity between the critical word and its associate are controlled for. Consequently, these data represent a major step forward in support of the QDR framework.

Previous visual-world experiments have demonstrated that when hearing a word, the eyes move faster and more frequently towards a depicted object whose conceptual representation overlaps with the representation of the named word. In those studies, however, the focus was on *featural* overlap among concepts (e.g., *piano-trumpet*;

Huettig & Altmann, 2005) or on contextual similarity-based connections (e.g., *bomb-cannon*; Huettig et al., 2006) which were exempt from associative relationships. Interestingly, as Altmann and Kamide (2007) proposed, the mental representations that drive participants' attention are based on various sources of information, also including associative relationships among concepts (see also Yee & Sedivy, 2006). Therefore, an attention shift is also expected to occur as a consequence of semantic association (see also McDonald & Shillcock, 2003). To our knowledge, the present experiment is the first to provide clear-cut evidence in support of this view.

As stated earlier, most theories draw the distinction between abstract and concrete words in terms of the amount of information involved (Paivio, 1986; Plaut & Shallice, 1991, 1993; Schwanenflugel & Shoben, 1983). The present results, however, cannot be easily accommodated by these theories. For example, the main prediction of the Context Availability theory (e.g., Kieras, 1978; Schwanenflugel et al., 1983, 1988) – that abstract words, when supported by enough context, are recognized as fast as concrete words – does not apply to the present experiment since subjects were always looking at arrays of concretely depicted objects. This theory would indeed predict no differences or differences in the opposite direction, with concrete words being recognized faster than abstract words in the spoken stream. A similar argument could be applied to the Dual Coding Theory (e.g., Paivio, 1971) which postulates that semantic information is represented in two different systems, one for sensorimotor and the other for verbal information. Both abstract and concrete words are represented in terms of verbal knowledge, while only the concrete words also benefit from additional sensorimotor knowledge. According to this view, the association effect between a concrete word and a concrete picture is expected to be greater than between an abstract word and a concrete picture. However, our findings reveal exactly the opposite pattern.

Given the nature of this visual-world experiment, it was not possible to include additional conditions whereby the critical abstract or concrete word is combined with semantically similar (rather than associated) visual targets in the display. This is because in such a design, an abstract word would have to be combined with a target picture that refers to a (semantically similar) abstract entity, which is naturally rather difficult to achieve. Instead, we ensured that our abstract vs. concrete word-associate pairs were, on average, comparable in terms of semantic similarity. The observed eye-movement effects can therefore not plausibly be attributed to whether, say, 'the smell' is semantically more similar to 'nose' (abstract word-associate pair) than 'crib' is to 'baby' (concrete word-associate pair). It should be noted, however, that in two very recent word recognition priming studies, we were able to investigate the effects of type of relation (association vs. semantic similarity) and type of word (concrete vs. abstract) in a fully crossed 2×2 design (Avilés, Duñabeitia & Carreiras, submitted; Müller, Avilés, Duñabeitia & Carreiras, 2008). In these experiments, we used sets of concrete and abstract prime and target words that were highly associated but semantically dissimilar (e.g., *egg*-*CHICKEN*; *effect*-*CAUSE*) and sets of concrete and abstract primes and targets that were synonymous but not associated (e.g., *car*-*VEHICLE*; *triumph*-*SUCCESS*), together with corresponding unrelated control conditions. At short SOAs (50 and 100 ms) these experiments revealed stronger associative priming effects for abstract rather than concrete words, and conversely, stronger semantic similarity priming effects for concrete rather than abstract words, resulting in a significant interaction between type of relation and type of word. These results are in line with the present findings, and altogether provide strong support for QDR framework. The present study, together with recent findings from different paradigms and techniques, demonstrate that abstract words make associated concepts more readily available than concrete words even if *quantitative* strength of association is controlled for.

Finally, there is a methodological issue which should be stressed. Just as in the previous two studies applying the *Logistic Power Peak* function to visual-world time series data (Scheepers, Keller & Lapata, 2008; McQueen & Viebahn, 2007), the *LPP* model achieved very good fits of the data, even though we were focusing on theoretically very different questions to those earlier studies. Hence, we believe that this function may indeed provide an excellent general tool for analysing the time course of effects in visual-world experiments.

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Appendix

VISUAL TARGETS, **related auditory** words, and *unrelated auditory* words used in the experiment.

Abstract: PAN-**pedazo**-*merced*, PLUMA-**ligereza**-*apoyarse*, RADIO-**difusión**-*abandono*, MUNDO-**creación**-*justicia*, PERIÓDICO-**artículo**-*fenómeno*, SOFÁ-**comodidad**-*monotonía*, REGALO-**detalle**-*dominio*, AJEDREZ-**partida**-*aparato*, MONEDA-**libra**-*pasmo*, MARTILLO-**herramienta**-*encarnación*, BOMBILLA-**idea**-*joven*, CAMIÓN-**carga**-*plano*, VESTIDO-**elegancia**-*facilitar*, IGLESIA-**pecado**-*horror*, TREN-**estación**-*universo*, LLUVIA-**temporal**-*descenso*, CASA-**piso**-*ropa*, MAR-**sirena**-*ojeada*, TELÉFONO-**llamada**-*oficial*, LÁPIZ-**punta**-*traje*, HELADO-**polo**-*goma*, MÉDICO-**consulta**-*longitud*, MONTAÑA-**relieve**-*acierto*, RÍO-**cauce**-*fruta*, CERDO-**lomo**-*tajo*, AVIÓN-**pasajero**-*travesía*, GUITARRA-**tocar**-*favor*, PERRO-**rabia**-*baile*, FUEGO-**infierno**-*aprender*, NARIZ-**olor**-*rato*, MAPA-**geografía**-*acusación*, PUERTA-**abrir**-*vuelo*, LÁMPARA-**luminosidad**-*militarismo*, BARCO-**hundimiento**-*estimulante*, COCHE-**velocidad**-*economía*, VELA-**cera**-*mina*, AUTOBÚS-**conductor**-*deportivo*, ÁGUILA-**rapaz**-*farsa*, FLOR-**capullo**-*folleto*.

Concrete: BARBA-**bigote**-*obispo*, BASTÓN-**ciego**-*varón*, CÍRCULO-**compás**-*chófer*, CUADRADO-**triángulo**-*vitaminas*, HUESO-**músculo**-*gallega*, NIÑA-**muñeca**-*anillo*, PIEDRA-**mármol**-*espada*, PISCINA-**nadar**-*horno*, PISTOLA-**pólvora**-*algodón*, QUESO-**ratón**-*litro*, BOLÍGRAFO-**estuche**-*caricia*, CUCHILLO-**navaja**-*zapato*, SILLA-**taburete**-*visillos*, PIE-**bota**-*soga*, BALÓN-**fútbol**-*plaza*, BEBÉ-**cuna**-*robo*, CARTA-**correo**-*senado*, CUERNO-**caracol**-*cantina*, GATO-**cascabel**-*persiana*, HUEVO-**gallina**-*difunto*, MANO-**puño**-*sopa*, MUJER-**marido**-*humano*, PESCADO-

espina-*legión*, SALVAVIDAS-**chaleco**-*cirugía*, CORAZÓN-**infarto**-*perfume*, ELEFANTE-**marfil**-*liebre*, BOTELLA-**tapón**-*tecla*, MÚSICA-**piano**-*gafas*, PÁJARO-**nido**-*pila*, CHAQUETA-**botón**-*nieto*, LLAVE-**candado**-*acuario*, DIENTE-**cepillo**-*vomitar*, PANTALÓN-**cinturón**-*gasolina*, CIGARRO-**cenicero**-*mariposa*, MESA-**mantel**-*violín*, CABALLO-**jinete**-*grieta*, VENTANA-**puerta**-*ciudad*, TOMATE-**lechuga**-*aguijón*, BRAZO-**pierna**-*hierba*.

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