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Deficits of semantic control produce absent or reverse frequency effects in comprehension: Evidence from neuropsychology and dual task methodology

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ABSTRACT

Patients with multimodal semantic impairment following stroke (referred to here as 'semantic aphasia' or SA) fail to show the standard effects of frequency in comprehension tasks. Instead, they show absent or even *reverse* frequency effects: i.e., better understanding of less common words. In addition, SA is associated with poor regulatory control of semantic processing and executive deficits. We used a synonym judgement task to investigate the possibility that the normal processing advantage for high frequency (HF) words fails to emerge in these patients because HF items place greater demands on executive control. In the first part of this study, SA patients showed better performance on more imageable as opposed to abstract items, but minimal or reverse frequency effects in the same task, and these negative effects of word frequency on comprehension were related to the degree of executive impairment. Ratings from healthy subjects indicated that it was easier to establish potential semantic associations between probe and distracter words for HF trials, suggesting that reverse frequency effects might reflect a failure to suppress spurious associations between HF probes and distracters. In a subsequent experiment, the aphasic patients' performance improved when HF probes and targets were presented alongside low frequency distracters, supporting this hypothesis. An additional study with healthy participants used dual task methodology to examine the impact of divided attention on synonym judgement. Although frequently encountered words were processed more efficiently overall, the secondary task selectively disrupted performance for high but not low frequency trials. Taken together, these results show that positive effects of frequency are counteracted in SA by increases in semantic control requirements for HF words.

1. Introduction

Semantic cognition – i.e., the selective use of meaning to guide behaviour according to the context or task – is underpinned by at least two interacting components: (a) semantic representations and (b) executive processes which help to direct and control semantic activation in a task-appropriate fashion (Jefferies and Lambon Ralph, 2006). These control processes play a vital role in semantic cognition because only particular aspects of our knowledge are relevant for a specific task or context. For example, we know that pianos are both heavy and played by pressing keys with the fingers: therefore if our task is to move a piano across the room, information about fine motor movements must be disregarded (Saffran, 2000).

These components of semantic cognition are associated with different neural substrates and can be impaired separately in different groups of brain-injured participants. Patients with semantic dementia (SD) have a degraded store of semantic knowledge following atrophy and hypometabolism focussed on the inferior anterior temporal lobes bilaterally (Galton et al., 2001; Mummery et al., 2000; Nestor, Fryer, & Hodges, 2006). This results in poor performance across the full range of verbal and non-verbal modalities and a high degree of consistency across tasks (Bozeat, Lambon Ralph, Patterson, Garrard, & Hodges, 2000; Garrard and Carroll, 2006). In contrast, stroke aphasia patients with multimodal comprehension problems (referred to below as 'semantic aphasia', abbreviated to 'SA') have infarcts affecting left posterior temporal, parietal and inferior frontal regions (Berthier, 2001; Chertkow, Bub, Deaudon, and Whitehead, 1997; Dronkers, Wilkins, Van Valin, Redfern, & Jaeger, 2004; Hart and Gordon, 1990; Hillis et al., 2001). Stroke rarely produces lesions of the most inferior portion of the ATL (i.e., the focus of brain atrophy in SD) because this is a watershed region which receives a blood supply from multiple arteries; moreover, one of these – the anterior temporal cortical artery – branches off the middle cerebral artery below its major trifurcation, making it less vulnerable to emboli (Borden, 2006).

In a number of previous studies, we have found that SA patients with multimodal comprehension problems have largely intact semantic knowledge but deregulated semantic cognition

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(Corbett, Jefferies, & Lambon Ralph, 2009; Jefferies and Lambon Ralph, 2006; Jefferies, Patterson, & Lambon Ralph, 2008). SA patients are inconsistent across tasks that require different types of semantic processing, even when the same concepts are probed. Unlike patients with SD, individuals with SA show strong benefits of cues that reduce the requirement for internally-driven semantic control (Jefferies et al., 2008; Hoffman, Jefferies, & Lambon Ralph, 2010; Noonan, Jefferies, Corbett, & Lambon Ralph, 2010). Their performance is strongly affected by the executive requirements of semantic tasks: they have difficulty selectively retrieving the task-relevant meanings of items and rejecting highly associated distracters (Corbett, Jefferies, and Lambon Ralph, 2011; Jefferies et al., 2008; Noonan et al., 2010). Moreover, while SD patients retain good executive skills, semantic deficits in SA are associated with impairments of attention/executive function (Baldo et al., 2005; Jefferies and Lambon Ralph, 2006; Wiener, Connor, & Obler, 2004).

These findings suggest that sites within left posterior temporal, parietal and inferior frontal regions form a large-scale distributed system that underpins the executive control of semantic processing. This view is further supported by functional neuroimaging and TMS studies of healthy participants. Although the functional neuroimaging literature has traditionally focussed on the contributions of left inferior frontal cortex (LIFC), many neuroimaging studies have, in fact, observed activation within posterior temporal and parietal cortex which is modulated by semantic control demands (e.g., Badre, Poldrack, Pare-Blagoev, Insler, & Wagner, 2005; Nagel, Schumacher, Goebel, & D'Esposito, 2008; Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997; Wagner, Pare-Blagoev, Clark, & Poldrack, 2001). We recently conducted a meta-analysis of functional neuroimaging studies which confirmed that LIFC, posterior middle temporal gyrus (pMTG) and portions of left parietal lobule are all reliably influenced by manipulations of semantic control (Noonan, Jefferies, Visser, & Lambon Ralph, submitted). Moreover, we demonstrated a functional dissociation between ATL and these sites within a single fMRI study utilising ambiguous words in a double-prime paradigm: ATL was sensitive to the number of meanings that were retrieved (consistent with a role for this region in semantic representation), while pMTG, inferior parietal cortex and LIFC showed greater activation when the dominant meanings of words had to be inhibited (suggesting they underpin semantic control; Whitney, Jefferies, and Kircher, 2011). This distributed activation was shown to be functionally significant using TMS: stimulation of LIFC, pMTG and IPL disrupted control-demanding comprehension tasks, but not more automatic semantic judgements (Whitney et al., 2011; Whitney, Kirk, O'Sullivan, Lambon Ralph, & Jefferies, 2012). The findings of these TMS studies are somewhat similar to studies of patients with SA, which reveal particular difficulties in control-demanding semantic tasks following lesions of either LIFC or temporoparietal regions (Jefferies & Lambon Ralph, 2006; Noonan et al., 2010).

Patients with SD and SA also show striking differences in the effect of frequency on comprehension which have been linked to the differential effects of this variable on representation and control demands (Hoffman, Jefferies, & Lambon Ralph, 2011a; Hoffman, Rogers, & Lambon Ralph, 2011b). Patients with SD show strong positive effects of frequency in a wide range of semantic tasks: frequently encountered items are better preserved than less frequent stimuli and retained for longer as the disease progresses (Bozeat et al., 2000; Funnell, 1995; Jefferies, Patterson, Jones, & Lambon Ralph, 2009; Lambon Ralph, Graham, Ellis, & Hodges, 1998). Similarly, in healthy participants, high frequency (HF) items have a substantial advantage because the system has a greater opportunity to learn how to process them accurately and efficiently (e.g., Forster & Chambers, 1973; Plaut, McClelland, Seidenberg, & Patterson, 1996). Therefore SD patients show an exaggeration of the normal frequency effect, presumably because representations of frequently encountered items are more robust to damage (Rogers et al., 2004). In contrast, frequency effects in SA are either absent (Jefferies, Baker, Doran, & Lambon Ralph, 2007; Jefferies & Lambon Ralph, 2006; Warrington & Cipolotti, 1996) or even reversed—i.e., performance can be better for low frequency (LF) items (Hoffman et al., 2011a, 2011b). This is surprising since we might expect higher frequency concepts to show greater resilience to impairment.

What might explain this difference between SD and SA patients in the effects of frequency? A partial explanation is provided by the notion that SA patients do not have a degraded semantic store—consequently, they would not be expected to show disproportionate damage to semantic representations corresponding to less frequent concepts. However, this cannot be a complete explanation because SA patients sometimes show *reverse* frequency effects. This suggests there is a processing cost for HF items, magnified in patients with SA, which overrides the normal processing advantage that frequent items enjoy. Given that SA patients have poor executive control over semantic activation, one possibility is that HF concepts require greater semantic control. HF words and objects are encountered in a wider range of situations and alongside a larger number of other items than LF words because they occur more commonly (Adelman, Brown, & Quesada, 2006; Hoffman et al., 2011a, 2011b). These varied semantic associations are likely to be activated automatically when a HF item is presented, yet many of them will be irrelevant to the task at hand—consequently, semantic processing for HF words might require greater executive control. This difference between HF and LF concepts is likely to be particularly prominent in tasks in which participants are asked to select which of several items is closest in meaning to a probe (i.e., in synonym judgement), because activation could potentially spread from the probe to the distracters as well as to the target. Therefore, although participants will be more efficient at retrieving the meanings of HF items, some of this information will need to be disregarded for the correct response to be made.

In this study, we investigated the hypothesis that absent or reverse frequency effects in SA reflects the greater demands that HF items place on executive control. In particular, patients with SA may fail to suppress spurious associations between HF probes and distracters in synonym judgement due to their deficits in semantic control. We confirmed absent or reverse frequency effects in a synonym judgement task in a sample of SA patients and then collected ratings from healthy participants which established that there were stronger semantic associations between probes and distracters for HF as opposed to LF trials. In a second experiment, we presented HF probes and targets alongside LF distracters, in order to establish whether SA patients would show better performance. This might be expected if these patients have difficulty suppressing irrelevant potential links between HF probes and distracters. Finally, we used dual task methodology with healthy participants to examine the impact of divided attention on synonym judgement for HF and LF words. To anticipate, we obtained convergent findings across these neuropsychological and dual task investigations: both indicated that semantic decisions to HF items are more demanding of executive control than decisions about LF concepts.

2. Experiment 1: Frequency and synonym judgement in SA patients

2.1. Method

2.1.1. Test construction

Participants were asked to select the word closest in meaning to a probe word. There were three choices per trial (the target plus two unrelated distracters). Simultaneous auditory and visual presentation was used and patients indicated their choice by pointing. There were 96 trials split evenly between two non-overlapping frequency bands (mean frequency of probe words (with standard deviations in parentheses) = 128 (1 0 2) and 4.6 (4.5) counts per million in the Celex database; Baayen, Piepenbrock, and van Rijn, 1993) and three non-overlapping imageability bands (mean imageability of probe words = 275 (17.3), 452 (26.0) and 622 (14.0), respectively, on a scale of 100–700). There were 16 trials in each of the six frequencies by imageability conditions. Both the targets and distracters were matched to the probe word for frequency and imageability. As a consequence, the trial as a whole (rather than just the probe word) varied frequency and imageability. Full details are provided in Jefferies et al. (2009).

2.1.2. Participants

We examined sixteen SA patients, most of whom participated in our previous investigations of the semantic control deficit in this condition (Corbett et al., 2009; Jefferies et al., 2007; Jefferies & Lambon Ralph, 2006; Jefferies et al., 2008; Noonan et al., 2010). The inclusion criteria were as follows: patients were all native speakers of British English; every case had brain injury and chronic impairment resulting from a cerebrovascular accident (CVA) at least a year previously; moreover, patients were only included if they showed evidence of *multimodal* semantic impairment affecting both words and pictures, for example on the Camel and Cactus test (Adlam, Patterson, Bozeat, and Hodges, 2010; Bozeat et al., 2000). Our previous studies using the same inclusion criteria found that SA patients with multimodal comprehension problems had concomitant executive deficits that were related to the degree of semantic impairment: in this study, we explored the negative effects of word frequency in a similar patient group. Table 1 shows neuroimaging summaries and aphasia classifications for the SA patients. Table 2a, 2b shows neuropsychological test scores on background semantic and non-semantic tasks.

The patients' semantic deficits were sometimes accompanied by additional impairments affecting fluency of speech and/or repetition (see Table 1 and 2a, 2b). Seven patients had transcortical sensory aphasia (TSA)—i.e., poor comprehension in the context of fluent speech and good repetition. The remainder had less fluent speech and/or poorer repetition in addition to their multimodal semantic impairment. MR images were available for nine cases (NY, SC, ME, KH, LS, DB, HN, GH, EC) and CT was available for three more (BB, KA, EW). It was not possible to obtain scans for three of the patients due to a lack of consent or contraindications for MRI, although written reports of previous CT scans were available for two of them (PG, JM). In line with the literature on semantic control deficits in stroke aphasia, all of the patients had left temporoparietal and/or prefrontal lesions (see Introduction). Further details of the patients' lesions are available in Jefferies and Lambon Ralph (2006) and Noonan et al. (2010).

2.2. Results

The synonym judgement data are shown in Fig. 1a. ANOVA was used to examine the effects of frequency and imageability on response accuracy. The SA patients showed a highly significant effect of imageability, $F(2,30)=37.3$, $p<0.0001$, but no effect of frequency overall, $F(1,15)<1$. The interaction between frequency and imageability approached significance, $F(2,30)=2.7$, $p=.08$. Bonferroni *t*-tests revealed that there was a reverse frequency effect for highly imageable items ($t(15)=2.7$, $p=.05$) but no significant frequency effect for either medium or low imageability items ($t(15)<1$).

Further analyses focused on the relevance of participant variables to synonym judgement performance. Factor analysis was used to extract a single factor score for (i) semantics (based on three comprehension tasks that every patient had completed: CCT words, CCT pictures and the Cambridge word-picture matching test, with the common factor accounting for 63.7% of the variance); (ii) executive function (based on the Brixton, Raven's Coloured Progressive Matrices and the TEA elevator counting task with distraction, replacing three missing scores with the group average; accounting for 53.7% of the variance); (iii) verbal short-term memory (based on PALPA 9 word repetition and

Table 1
Aphasia classifications and neuroimaging summaries for the SA participants.

Patient	Age	Edu	Neuroimaging summary	Aphasia type	BDAE compreh	BDAE fluency	BDAE repetition	Nonword repetition	Word repetition
HN	80	15	L occipital-temporal	Anomic/TSA	NT	NT	NT	56	86
EW	74	15	L occipital-temporal		NT	NT	NT	NT	80
JD	81	16	Compression of L lateral ventricle & capsular	Mixed transcortical	NT	NT	NT	73	93
SC	80	16	L occipital-temporal (+small R frontal infarct)	Anomic/TSA	37	90	60	87	98
ME	40	16	L occipital-temporal	TSA	33	100	100	93	100
GH	56	18	L frontal-parietal	Global	NT	NT	NT	NT	NT
NY	67	15	L frontal-parietal	Conduction	47	37	40	40	81
PG	63	18	L frontal & capsular	TSA	20	40	80	73	91
JM	69	18	L frontal-parietal	TSA	22	63	40	87	95
MS	73	14	No scan	Global	10	0	0	0	0
KH	73	14	L frontal-parietal-occipitotemporal	Mixed transcortical	30	30	40	43	80
KA	78	14	L frontal-parietal	Global	0	23	0	0	0
BB	59	16	L frontal	Mixed Transcortical	10	17	55	83	96
DB	76	16	L frontal-temporal-parietal	TSA/Wernicke's	13	90	30	70	85
LS	75	15	L frontal-parietal-occipitotemporal	TSA	13	90	90	90	96
EC	71	16	L frontal-parietal	Global	NT	NT	NT	NT	16

Patients are arranged in order of synonym judgement performance. BDAE = Boston Diagnostic Aphasia Examination (Goodglass, 1983). BDAE Comprehension score is a percentile derived from three subtests (word discrimination, commands, complex ideational material). BDAE Fluency percentile is derived from phrase length, melodic line and grammatical form ratings. BDAE Repetition percentile is average of word and sentence repetition. TSA (transcortical sensory aphasia) was defined as good or intermediate fluency/repetition and poorer comprehension. Word/nonword repetition: Tests 8 and 9 from PALPA (Psycholinguistic Assessments of Language Processing in Aphasia, Kay, Lesser, and Coltheart, 1992).

forwards digit span, replacing one missing value with the group average, accounting for 94.2% of the variance) and (iv) visual processing (based on the VOSP dot counting, position discrimination and number location subtests, replacing three missing values with the group average, accounting for 58.5% of the variance).

We then used Pearson's correlation to examine the association between these factor scores and the synonym task (all *p* values are two-tailed unless otherwise stated). There was no relationship between overall accuracy on the synonym task and the effects of frequency (i.e., the difference in accuracy between HF and LF

Table 2a
Background semantic test scores for the SA patients.

	Synonym judgement					CCT words	CCT picture	Picture naming	Word-picture matching	Category fluency	Sound – picture matching	Spoken word – picture matching	Sound-written word matching
	Total	*HF*	*LF*	HI	LI								
Max	96					64	64	64	64	-	48	48	48
Control mean	93.1					60.7	58.9	62.3	63.7	95.7	41.2	47.8	NT
Control SD	2.47					2.06	3.1	1.6	.5	16.5	2.5	0.6	
HN	90	47	43	32	27	*54	54	*50	*50	64	*36	*16	42
EW	*76	38	38	32	19	*48	*45	*45	*57	63	*22	*45	38
JD	*73	33	40	26	20	*38	*38	*49	*59	64	*31	*23	*46	47
SC	*71	36	35	29	14	*56	*47	*48	*59	*17	*32	*41	48
ME	*71	38	33	27	17	*34	*13	*4	*50	*25	*33	*40	40
GH	*71	32	39	29	17	*29	*45	*19	*60	*15	NT	NT	NT
NY	*69	33	36	28	15	*39	*36	*55	*60	*25	*28	*40	47
PG	*69	33	36	29	19	*40	*44	*46	*58	*4	*33	47	44
JM	*69	30	39	26	20	*37	*37	*30	*53	*20	*24	*43	NT
MS	*65	34	31	30	19	*42	**37	*0	*46	*0	NT	NT	NT
KH	*61	34	27	26	14	*41	*46	*29	*54	*21	*30	*44	NT
KA	*60	31	29	25	19	*36	*46	*0	*26	NT	*22	*21	36
BB	*58	27	31	24	15	*30	*38	*10	*54	*13	*26	*33	26
DB	*54	29	25	26	12	*33	*39	*4	*46	*9	*21	*36	NT
LS	*51	23	28	23	15	*16	*16	*5	*37	*11	*27	*35	33
EC	*41	20	21	17	14	*20	*32	*1	*40	NT	NT	NT	NT

Patients are arranged in order of synonym judgement performance. Table shows raw scores. Max=maximum score.

* Denotes impaired performance (<2 SD from control mean). Data for controls and many patients taken from Corbett et al. (2009). CCT=Camel and Cactus Test of semantic association (Bozeat et al., 2000). CCT, picture naming, word-picture matching, category and letter fluency taken from Cambridge semantic battery (Adlam et al., 2010). In the sound-picture, spoken word-picture and sound-written word matching tests, patients listened to environmental sounds or spoken words and chose which printed picture or written word (out of 10 options) matched this auditory stimulus (Bozeat et al., 2000).

Table 2b
Background non-semantic test scores for the SA patients.

	Digit span (forwards)	Digit span (backwards)	VOSP: dot counting	VOSP: position discrimination	VOSP: number location	VOSP: cube analysis	Letter fluency	Brixton spatial anticipation (correct)	TEA Elevator counting (no distraction)	TEA Elevator counting (distraction)	Raven's coloured matrices
Maximum	–	–	10	20	10	10	–	55	7	10	36
Control mean	–	–	–	–	–	–	44.2	–	–	–	–
Control SD	–	–	–	–	–	–	11.2	–	–	–	–
Normal cut-off	5	2	8	18	7	6	–	28	6	3	–
HN	6	2	*8	19	9	*4	*19	28	7	9	20
EW	*4	2	10	20	10	7	*19	28	7	9	20
JD	5	2	10	20	10	10	* 5	28	7	6	30
SC	6	2	10	*17	10	9	*24	*25	7	*1	22
ME	6	3	*3	*15	*2	*4	*14	*11	7	9	13
GH	*2	*0	10	*4	*0	*0	*2	*18	6	*1	32
NY	*3	2	10	20	10	*5	* 5	34	*3	*2	26
PG	6	2	*5	20	9	10	* 2	*26	*3	*0	23
JM	*3	2	10	19	*5	*3	* 1	NT	*3	*0	14
MS	NT	NT	NT	NT	NT	NT	* 0	*16	NT	NT	12
KH	*4	2	10	*18	9	*3	* 1	*7	6	3	12
KA	0	NT	TA	*14	*6	TA	* 0	*6	NT	NT	12
BB	5	*0	10	*18	8	*2	* 0	*23	*4	*0	24
DB	*4	2	*6	TA	10	*3	*1	*24	*3	*1	31
LS	*4	*1	*6	*16	8	*4	*8	*14	*3	*2	16
EC	NT	NT	*3	*14	10	*6	NT	*24	*1	*1	12

Patients are arranged in order of synonym judgement performance. Table shows raw scores.

* Denotes impaired performance (<2 SD from control mean). Data for controls and many patients taken from Corbett et al. (2009). VOSP=Visual Object and Space perception Battery (Warrington and James, 1991). Brixton spatial anticipation test (Burgess & Shallice, 1997). TEA=Test of Everyday Attention (Robertson, Ward, Ridgeway, and Nimmo-Smith, 1994). Raven's coloured matrices (Raven, 1962).

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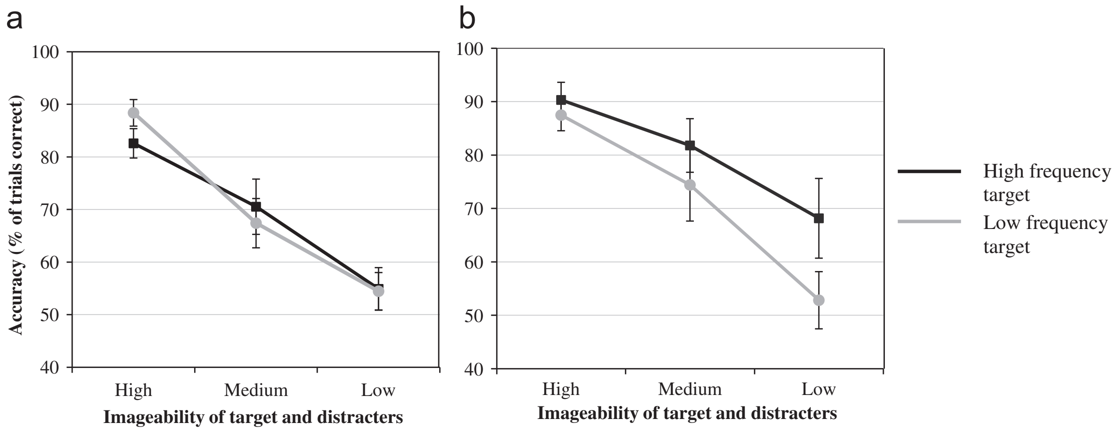

Fig. 1. Effects of frequency, imageability and distracter type on standard synonym judgement accuracy for SA patients (Experiments 1 and 3). (a) Standard synonym judgement (Experiment 1) and (b) Reverse frequency distracters (Experiment 3). Error bars show SE of mean.

trials; $r<.1$) or imageability (difference between HI and LI trials; $r=.15$, n.s). Overall performance on the synonym task showed a highly significant correlation with the semantic factor ($r=.74$, $p=.001$), no correlation with the executive factor ($r=.23$, n.s.) or the visual factor ($r<.1$) and a correlation with the verbal short-term memory factor that approached significance ($r=.44$, $p=.09$). This presumably reflected the fact that participants had to hold in mind several words whilst making their decision, especially if their reading was compromised. The effects of word frequency and imageability in synonym judgement did not correlate with any of the factor scores ($r<.36$, n.s.) with one exception: there was a negative correlation between the effect of frequency and the executive factor score ($r=-.46$, $p=.04$, one-tailed p). This shows, as predicted, that reverse effects of frequency on the synonym judgement task were associated with poorer scores on executive tasks. There was also a near-significant positive correlation between the executive and semantic factor scores ($r=-.41$, $p=.056$, one-tailed p), in line with previous findings for SA patients (Baldo et al., 2005; Jefferies & Lambon Ralph, 2006; Wiener et al., 2004), but no significant correlations between the pair-wise combinations of the other factor scores ($r<.39$, $p>.14$).

3. Experiment 2: Ratings from healthy participants

In the next study, we explored the possibility that HF trials in the synonym judgement task might place greater demands on executive semantic processing due to the fact that these words appear in more contexts and, as a result, have richer and more variable meanings. Hoffman et al. (2011b) were able to relate a measure of meaning diversity to synonym judgement performance in patients with SA. They found that semantic diversity was higher for words (i) low in imageability and (ii) high in frequency. They proposed, in line with our hypothesis, that the strong correlation between word frequency and semantic diversity explains why the standard frequency effect is not observed in this group. When semantic diversity was taken into account in an item analysis, a small positive effect of frequency emerged.

Here, we extend these ideas to look at the strength of potential links between probe and distracter words. For semantically diverse HF words, task-irrelevant associations between probes and distracters might be more likely to be retrieved than for LF words with less diverse meanings. SA patients with semantic control deficits might have difficulty disregarding these associations as a basis for their decisions, reducing, eliminating or even reversing the standard HF advantage. To look directly at this possibility, we asked healthy participants to rate the ease with which they could generate a semantic link between the HF and LF probes and *distracters* used in Experiment 1.

3.1. Method

3.1.1. Participants

The participants consisted of 36 healthy undergraduate students from the University of York. Their ages ranged between 19–22 years old. There were 24 females and 12 males. All were native speakers of British English.

3.1.2. Procedure

Participants were asked to indicate how readily they could form a semantic association between two words. They indicated their answer on a scale from 1 to 5, where 1 corresponded to no clear link between those words and 5 indicated immediate retrieval of a strong link. Participants were presented with 192 pairs of words listed on paper: these corresponded to the 96 probe words from Experiment 1 combined with the two distracters (presented in separate trials). Participants wrote their answer in a box next to each pair of words. The five-point scale was visible at the top of the answering sheet.

3.2. Results

Table 3 shows average ratings for each frequency by imageability condition in the synonym judgement experiment. We used linear regression to examine the relationship between log frequency and imageability (for the probe words) and probe-distracter association ratings (averaged across the two distracters presented with the same probe). R^2 for the model was .223. Log frequency was the strongest predictor of probe-distracter association strength ($\beta=.46$, $p<.0001$): participants found it easier to identify potential associations for HF probes and their distracters. There was also a weaker negative relationship with imageability ($\beta=-.18$, $p=.05$), reflecting stronger probe-distracter associations for more abstract words. These findings mirror the relationships between semantic diversity and frequency/imageability reported by Hoffman et al. (2011b). HF and abstract words have more diverse meanings, stronger connections with supposedly unrelated distracters, and produce poorer performance in SA patients with impaired semantic control.

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Table 3
Ratings from healthy participants of the ease of forming a semantic association between high and low frequency targets and distracters (Experiment 2).

Conditions	Mean	s.d.
High frequency; high imageability	2.21	.77
High frequency; medium imageability	2.30	.68
High frequency; low imageability	2.27	.70
Low frequency; high imageability	1.79	.59
Low frequency; medium imageability	1.95	.59
Low frequency; low imageability	1.97	.58

Ratings are on a scale of 1–5, where 1 represents no clear link between the words and 5 indicates immediate retrieval of a strong link.

4. Experiment 3: Frequency-reversed distracters in SA patients

If stronger associative links between HF probes and distracters are overriding positive effects of frequency in synonym judgement for individuals with SA, patients should show paradoxically better performance on HF trials which incorporate LF distracters (as this should discourage the activation of task-irrelevant associations). LF trials are not expected to show strong effects of reversing the frequency of distracters, because these items are less likely to activate spurious associations in the first place.

4.1. Method

The experiment used the same target words and testing format as the test above. The sole difference was that the HF probes/targets were presented with the LF distracters, whereas the LF probes/targets were tested in conjunction with HF distracters. The imageability of the distracters was still matched to the probe/target. Eleven SA patients completed the reverse frequency experiment (MS, KH, JM, EC and GH were not available to take part).

4.2. Results

The results are shown in Fig. 1b. The data were analysed using a $2 \times 2 \times 3$ within-subjects ANOVA incorporating frequency (HF vs. LF), imageability (high, medium and low) and distracter type (standard vs. reversed distracters). There was a significant main effect of imageability, $F(2,20)=43.8$, $p<0.0001$, and distracter type, $F(1,10)=10.0$, $p=0.01$. There was no main effect of frequency ($F(1,10)=2.0$, $p=0.2$). In line with our predictions, there was a highly significant frequency by distracter type interaction ($F(1,10)=11.1$, $p=0.008$). Planned *t*-tests showed that the SA group performed more accurately for HF items when they were presented with LF distracters, compared with their performance in the standard synonym judgement test used in Experiment 1 ($t(10)=4.2$, $p=.002$). Reversing the frequency of the distracters did not affect accuracy for the LF items ($t(10)<1$). No other interactions approached significance ($F<1.8$). The SA patients showed a significant positive effect of frequency in the reversed distracter condition overall, $F(1,10)=6.3$, $p=0.03$).

5. Experiment 4: Synonym judgement under dual task conditions

The findings above are consistent with our hypothesis that semantic judgements to HF words place greater demands on executive control than judgements to LF words—and therefore deficits in semantic control in patients with SA produce absent or reverse frequency effects in this patient group. If this proposal is correct, it might be possible to simulate the performance of SA patients in healthy individuals by using a secondary task to divide attention during synonym judgement. We predict that healthy participants should show a processing advantage for HF words overall (reflecting the language system's substantial experience for these items); however, the secondary task should produce greater disruption to semantic judgements about HF as opposed to LF words.

5.1. Method

5.1.1. Participants

36 healthy undergraduate students aged 19–22 years (24 females) participated for a small cash payment or course credit. All participants were native speakers of British English.

5.1.2. Design

We used a within-subjects design. A computerised version of the synonym judgement task from Experiment 3 was employed, involving written words and key press responses. On some trials, participants made semantic judgements alone, while in other trials they simultaneously performed an auditory-verbal 1-back task. There were four versions of the experiment which presented the same items in four different conditions generated by a 2×2 design (single vs. dual task; frequency-matched vs. frequency-reversed distracters). Every item was presented in each condition across participants (nine subjects per version). Items were not repeated for individual participants.

For each participant, the experiment was presented in 3 blocks: (i) 1-back task under single task conditions; (ii) synonym judgement, with half of the trials requiring simultaneous 1-back performance (dual and single-task trials were presented in a mixed fashion), (iii) a final block of 1-back trials under single task conditions.

5.1.3. Procedure

The experiment was presented using E-prime. All the instructions were delivered via the computer with examples at the beginning of each task.

In the blocks involving the 1-back task on its own, a series of random digits from 1–9 were presented through speakers at a rate of 1.5 s. Participants listened to the first number without responding, and for each subsequent number, they attempted to say the item that they heard on the previous trial. For example: "9" → listen; "6" → Say 9; "1" → Say 6. A fixation cross was presented on the screen while the participants repeated the numbers and they controlled the presentation of the next trial by pressing a key. In the initial block, there were 12 practice trials followed by a further 12 trials used as a baseline measure of 1-back performance prior to the synonym task.

Next, participants were given practice on the synonym task (with and without a concurrent secondary task). The probe word was presented at the top of the computer screen with three choices beneath. Participants pressed 1, 2 or 3 on the keyboard to respond (where the location of the target on the screen corresponded to the location of the keys on the keyboard). They were asked to respond as quickly and accurately as possible. Participants completed 96 experimental trials, 48 under single task conditions, and 48 requiring simultaneous 1-back performance, presented in a mixed fashion. Participants were unable to anticipate in advance which synonym trials would be presented under single and dual task conditions; instead, they were instructed to start doing the 1-back task if a number sequence was presented. After a variable interval (3–5 digits in the 1-back sequence), the synonym words were presented while the 1-back task continued; in contrast, in single-task synonym trials, the synonym judgement was presented visually after fixation, in the absence of a number sequence. Again, participants controlled the presentation of each trial by pressing a key on the keyboard.

Following the synonym task, participants performed the 1-back task under single task conditions again. Two 'warm-up' trials were followed by twelve assessment trials. The two 1-back only blocks (at the beginning and end of the experiment) were averaged together to provide a measure of 1-back single task performance.

5.2. Results

5.2.1. RT for synonym judgement

We used repeated-measures ANOVA to examine the effects of word frequency (high/low), distracter type (standard/reverse) and dual task (single/dual) on response times (RT). The results are shown in Table 4 and Fig. 2. The main effect of dual task was significant, $F(1,35)=5.3$, $p=.03$, as was the effect of frequency, $F(1, 35)=9.6$, $p=.004$)—healthy participants responded more quickly to HF than LF words. There was no main effect of distracter type, $F(1,35)=1.06$. The predicted interaction between dual task and frequency reached significance, $F(1, 35)=4.1$, $p=.05$ (see Fig. 2). There was an effect of the dual task on RT for HF words which approached significance (Bonferroni $t(35)=3.11$, $p=0.08$), but no effect for LF words ($t(35)=1.4$). This suggests that semantic decisions to HF words require greater executive control than those to LF words, in line with our findings from SA patients.

Table 4
Effect of frequency, imageability, distracter type and dual task on RT for healthy participants (Experiment 4).

	Single task	Dual task
HF standard distracters	1997.34 (666.98)	2234.07 (979.95)
LF standard distracters	2277.72 (982.78)	2412.75 (937.03)
HF reverse distracters	1979.67 (695.83)	2346.46 (772.80)
LF reverse distracters	2369.72 (1218.17)	2482.18 (1177.97)
High imageability	1855.88 (2344.91)	2130.68 (2281.17)
Medium imageability	2053.37 (2748.96)	2251.632 (2754.21)
Low imageability	2545.20 (2751.61)	2678.49 (3026.95)

Figures show mean (standard deviation in parentheses). HF=High frequency; LF=Low frequency.

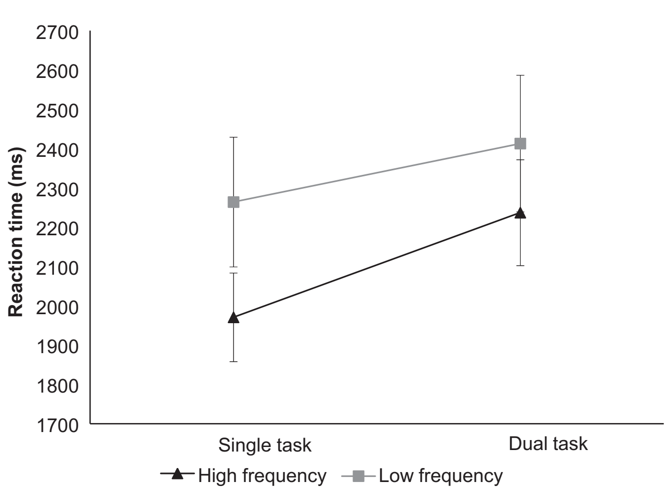

Fig. 2. RT for healthy participants in the dual task experiment, showing effects of frequency, distracter type and divided attention (Experiment 4). Error bars show SE of mean.

In a separate RT analysis, we also examined the effect of imageability and dual task, collapsing across distracter type to boost the number of trials per condition (see Table 4). Decisions about highly imageable words were significantly faster than for more abstract items, $F(2,68)=40.6$, $p<.0001$. No other effects or interactions reached significance.

5.2.2. Accuracy of synonym judgement

Our primary outcome measure was RT since the accuracy of the healthy participants approached ceiling. Nevertheless, in a repeated-measures ANOVA of response accuracy, including frequency, distracter type and dual task as factors, there were main effects of dual task ($F(1,35)=45.2$, $p<.0001$), frequency ($F(1,35)=47.9$, $p<.0001$) and distracter type ($F(1,35)=7.01$, $p=.012$) but no significant interactions ($F(1,35)$, $F<1$). These results are shown in Table 5. Participants were more accurate overall on reverse distracter trials, apparently because they did better on LF trials when these probes and targets were presented with HF distracters (they were close to ceiling on HF synonym judgement).

Following the method above, we also carried out a separate analysis including imageability and dual task as factors: this revealed main effects of both imageability ($F(2,70)=70.4$, $p<.0001$) and the secondary task ($F(1,35)=38.4$, $p<.0001$), plus a significant interaction between them ($F(2,70)=3.2$, $p=.05$). The secondary task reduced accuracy for low imageability (Bonferroni $t(35)=4.2$, $p<.001$) and medium imageability words (Bonferroni $t(35)=3.4$, $p=.004$), while there was no significant effect of the 1-back task for high imageability items (Bonferroni $t(35)=1.7$, n.s.). The more challenging abstract items may have shown the largest influence of the dual task because they were less influenced by ceiling effects.

5.2.3. 1-back performance

We analysed the percentage of 1-back responses that were correct for each participant, averaged across all of the trials within each condition. The results are shown in Table 6. Repeated-measures t-tests contrasting single task performance in the initial and final 1-back blocks showed significant improvement across the experiment, $t(35)=3.47$, $p=.001$. 1-back performance was significantly more accurate under single task conditions (using an average of the initial and final 1-back blocks) than during synonym judgment overall, $t(35)=7.6$, $p<.001$. We used repeated-measures ANOVA to examine the effect of frequency and distracter type manipulations within the synonym task on 1-back secondary task performance. This confirmed that 1-back performance was worse during LF than HF trials, $F(1,35)=17.49$, $p<.001$, presumably because LF items were more difficult overall. There was no effect of distracter type and no frequency by distracter type interaction. In addition, a one-way repeated-measures ANOVA indicated a

Table 5
Effect of word frequency, imageability, dual task and distracter type on synonym judgement accuracy for healthy participants (Experiment 4).

	Single task	Dual task
HF standard distracters	95.13 (6.09)	87.50 (9.86)
LF standard distracters	81.01 (16.85)	76.15 (15.57)
HF reverse distracters	95.60 (6.45)	91.43 (9.85)
LF reverse distracters	84.95 (12.25)	79.62 (14.96)
High imageability	97.32 (1.76)	96.20 (2.02)
Medium imageability	93.08 (3.06)	88.83 (3.36)
Low imageability	81.47 (3.51)	72.76 (3.75)

Table shows mean accuracy on the synonym task, as a percentage of the total trials in each condition (standard deviation in parentheses). HF=high frequency, LF=low frequency.

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Table 6
1-back accuracy for healthy participants in the dual task experiment (Experiment 4).

	Mean	s.d.
Baseline 1	91.96	8.14
Baseline 2	96.01	4.01
Baseline average	93.80	5.78
HF Standard distracters	77.26	18.59
HF Reverse distracters	80.14	18.03
LF Standard distracters	72.91	17.37
LF Reverse distracters	73.50	16.27

Baseline = performance on 1-back task performed in isolation. HF = high frequency, LF = low frequency. Table shows accuracy on the 1-back task, expressed as a percentage of items presented.

significant effect of imageability on 1-back performance, $F(2,70)=5.1$, $p=.009$. Bonferroni t tests revealed that 1-back performance was better during synonym judgement for high as opposed to low imageability trials, $t(35)=3.0$, $p=.01$, presumably because the LI items were also more difficult. No other pairwise comparisons reached significance.

6. General discussion

This study examined the hypothesis that decisions about the meanings of high frequency (HF) words require greater executive control than semantic decisions for low frequency (LF) words. HF words occur in more contexts and have wider and more variable meanings than their LF counterparts. In contrast, LF words are associated with a limited range of linguistic contexts and so similar semantic information is encountered each time (Hoffman et al., 2011b). Greater executive control might be required for HF words in order to selectively focus processing on aspects of meaning that are relevant for a given task or context. This is likely to be particularly evident in a task like synonym judgement, in which it is necessary to select one of several possible targets on the basis of their strength of association with the probe word—high frequency probes might be more likely to activate spurious or irrelevant associations. Patients with semantic aphasia (SA), who have poor executive control over semantic processing, might therefore show a reduction or elimination of the natural processing advantage enjoyed by high frequency items in synonym judgement, or possibly even a reversal of the normal frequency effect.

Over four experiments, we sought convergent evidence for these hypotheses from neuropsychology and healthy participants tested under dual-task conditions. In Experiment 1, SA patients showed minimal or reverse frequency effects, yet better performance for more imageable as opposed to abstract items within the same task, suggesting that our methods were sensitive to the influence of lexical variables on comprehension in SA. The negative effects of comprehension in the SA group were correlated with the degree of executive impairment, in line with our predictions. Moreover, we previously confirmed that the frequency manipulation in this test had a powerful *positive* influence on comprehension in another patient group (semantic dementia)—therefore SD and SA patients show a double dissociation (Jefferies et al., 2009).

In Experiment 2, healthy participants were asked to rate the ease with which they could think of associations between HF and LF probes and their supposedly unrelated distracters. The ratings showed that it was easier to think of a potential relationship between high frequency probes and their distracters: for example, in the HF trial "child with kid, road or university?", one might imagine a child playing in the road, or a grown-up child at university and consequently miss the synonymous relationship. In contrast, participants found it harder to think of a semantic relationship between low frequency targets and distracters.

Experiment 3 showed that when SA patients were presented with a version of the synonym task with frequency-reversed distracters—i.e., HF probes/targets with LF distracters and LF probes/targets with HF distracters, their performance on HF trials improved. We propose that the SA patients were less likely to respond on the basis of spurious associations when the HF probes were presented with LF distracters because LF words have less varied meanings and occur in fewer contexts (Hoffman et al., 2011b).

Finally, Experiment 4 provides support for our hypotheses in a sample of healthy participants. They carried out the same synonym judgement task as the patients but, on some trials, concurrently performed an auditory-verbal 1-back task. This requirement to perform two tasks simultaneously was designed to divide attention and reduce capacity for executive processing. The results showed that although HF words were less demanding for normal volunteers to process *overall* (resulting in standard frequency effects in response times), dual task conditions produced greater disruption for HF trials. This pattern is similar to that seen in patients with SA and confirms the view that HF words require greater cognitive control. However, the healthy volunteers continued to show near-ceiling accuracy in synonym judgement even under dual task conditions: consequently, the behavioural effects were seen in RT.

Given that the SA patients showed better performance on HF probes/targets when they were presented with LF distracters, it is worth noting that the healthy volunteers in Experiment 4 did not show an effect of frequency-reversed distracters on RT. A possible explanation for this null result is that SA patients are more vulnerable to errors induced by high frequency distracters due to their severely impaired semantic control. In contrast, healthy participants showed near-ceiling performance for HF trials, even under dual task conditions—positive effects of frequency were more prominent for them in both RT and accuracy. Although the secondary task did allow us to see negative effects of frequency in normal individuals *in RT*, any positive impact of the reverse distracter manipulation on HF items may have been swamped by the processing costs associated with presenting LF distracters, which would have taken longer to read and understand.

Taken together, these findings indicate that although HF items normally enjoy a processing advantage – perhaps reflecting more efficient reading processes and/or faster retrieval of associated meanings – they also place greater demands upon executive processes that direct semantic activation in a task-appropriate way. As a consequence, the standard frequency effect is eliminated and, in some cases/trials, even reversed in SA patients. This follows from the fact that (i) SA patients do not have damage to semantic representations in the anterior temporal lobes (unlike patients with semantic dementia; see Introduction)—consequently the resilience of HF representations to damage does not give rise to better preserved comprehension for HF items in SA. (ii) In addition, poor control over semantic activation in SA overrides the normal frequency advantage by disadvantaging HF trials more than LF trials. HF stimuli are observed in a greater variety of contexts/situations and have a greater diversity of meanings (Hoffman et al., 2011b): therefore, executive control is required to select the aspects of meaning that are relevant in a specific situation. In addition, executive control is required to ignore spurious links between the probe and distracter words in synonym judgement.

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7. Appendix A

See Table A1.

8. Appendix B

See Table A2.

Table A1
Standard synonym task (Experiment 1).

Image	Freq	Target	Response1	Response2	Response3
High	High	Winter	**Summer**	Sea	Clothes
High	High	Coffee	Neck	Key	**Tea**
High	High	Plant	Heart	**Tree**	Window
High	High	Telephone	**Radio**	Knife	Dog
High	High	Student	Radio	**Pupil**	Summer
High	High	Child	University	Road	**Kid**
High	High	Valley	**Hills**	Baby	Ship
High	High	Road	Student	**Street**	Fire
High	High	Bedroom	Grass	Artist	**Kitchen**
High	High	Mother	Money	Bed	**Parent**
High	High	Forest	**Woods**	Wine	Boat
High	High	Window	Eye	**Door**	Plant
High	High	River	**Stream**	Doctor	Square
High	High	Sun	Horse	**Moon**	Bridge
High	High	Money	Car	Church	**Cash**
High	High	Rock	Winter	Bottle	**Stone**
Low	High	Cause	Consider	Return	**Make**
Low	High	Value	Purpose	**Price**	Effect
Low	High	Proper	**Appropriate**	Apparent	Limited
Low	High	Reason	Value	**Explanation**	Influence
Low	High	Keep	Become	Put	**Save**
Low	High	Ordinary	**Normal**	Previous	Significant
Low	High	Advantage	Tendency	Condition	**Benefit**
Low	High	Significant	Normal	**Important**	Ordinary
Low	High	Basic	Recent	**Simple**	Considerable
Low	High	Constant	**Regular**	Essential	Aware
Low	High	Effect	Reason	Difference	**Consequence**
Low	High	Factor	**Part**	Advantage	Instance
Low	High	Average	Latter	Actual	**Typical**
Low	High	Consider	Develop	**Think**	Determine
Low	High	Function	**Purpose**	Responsibility	Extent
Low	High	Tendency	**Trend**	Factor	Concept
Med	High	Distance	**Length**	Scene	Health
Med	High	Clean	**Wash**	Pass	Send
Med	High	Strength	Literature	**Power**	Temperature
Med	High	Ancient	Sharp	Sweet	**Old**
Med	High	Fashion	Shelter	Column	**Style**
Med	High	Religion	Design	**Faith**	Growth
Med	High	Private	Single	**Personal**	Strong
Med	High	Society	**Public**	Period	Air
Med	High	Problem	Law	**Difficulty**	Service
Med	High	Freedom	Aid	**Independence**	Month
Med	High	Broad	**Wide**	Fresh	Evil
Med	High	Education	Front	Department	**Teaching**
Med	High	Pair	Childhood	**Couple**	Master
Med	High	Property	**Building**	Committee	Research
Med	High	Master	Edge	Enemy	**Professor**
Med	High	Pattern	Conference	Performance	**Design**
High	Low	Necklace	**Choker**	Lemonade	Geese
High	Low	Tulip	Banana	**Daffodil**	Alligator
High	Low	Butterfly	Gym	Volcano	**Moth**
High	Low	Kitten	Sunburn	Ski	**Gosling**
High	Low	Lobster	**Crayfish**	Bracelet	Helmet
High	Low	Kite	Zipper	Squirrel	**Toy**
High	Low	Chestnut	Swamp	**Conker**	Eagle
High	Low	Shrimp	**Prawn**	Nun	Pyramid
High	Low	Frog	Pickle	**Toad**	Jewel
High	Low	Ambulance	Wallet	Ant	**Lifeboat**
High	Low	Revolver	**Pistol**	Mist	Sunset
High	Low	Helmet	Caterpillar	**Headdress**	Scissors

Table A1 (*continued*)

Image	Freq	Target	Response1	Response2	Response3
High	Low	Jewel	Harp	**Gem**	Lobster
High	Low	Zipper	**Fastener**	Raspberry	Mosquito
High	Low	Puppy	Cider	**Kitten**	Peach
High	Low	Violin	Rabbit	Shed	**Viola**
Low	Low	Audit	Enigma	**Inspection**	Derivation
Low	Low	Protocol	Allegory	**Etiquette**	Debacle
Low	Low	Alias	Reprisal	Condescension	**Pseudonym**
Low	Low	Arbiter	**Mediator**	Undertaking	Reformation
Low	Low	Impetus	Equity	Misconception	**Motivation**
Low	Low	Despot	Unreality	**Tyrant**	Disclosure
Low	Low	Bequest	Chronology	Complication	**Legacy**
Low	Low	Criterion	**Norm**	Suffix	Resumption
Low	Low	Suffix	Perpetrator	Temerity	**Inflection**
Low	Low	Dirge	**Lament**	Emanation	Rarity
Low	Low	Deity	Incredulity	Vitriol	**Divinity**
Low	Low	Fallacy	Impropriety	**Myth**	Conjugation
Low	Low	Interim	**Temporary**	Indifferent	Reciprocal
Low	Low	Verity	**Certainty**	Artifice	Mediocrity
Low	Low	Morass	Substratum	**Mire**	Gist
Low	Low	Attribute	Complication	Preference	**Trait**
Med	Low	Omen	**Portent**	Recess	Benzene
Med	Low	Quake	Buyer	**Tremor**	Infinity
Med	Low	Adultery	Relic	Molecule	**Infidelity**
Med	Low	Wicket	Rubble	Flora	**Pitch**
Med	Low	Enamel	Molasses	Labyrinth	**Coating**
Med	Low	Gallant	**Heroic**	Fertile	Tame
Med	Low	Emulsion	**Paint**	Titbit	Riddle
Med	Low	Expanse	Canon	**Vastness**	Duel
Med	Low	Rogue	Polka	**Scoundrel**	Gasket
Med	Low	Crush	**Squash**	Gasp	Blink
Med	Low	Gentry	**Squire**	Sedative	Perch
Med	Low	Cartilage	Dowry	Madness	**Gristle**
Med	Low	Humour	Whiff	Carbohydrate	**Wit**
Med	Low	Boredom	Recruit	**Dullness**	Token
Med	Low	Hostility	Siege	**Aggression**	Oath
Med	Low	Opponent	**Foe**	Evolution	Optimism

Correct responses are shown in bold text.

Table A2
Frequency-reversed distracters synonym task (Experiment 3).

Image	Freq	Target	Response1	Response2	Response3
High	High	Coffee	Lobster	Harp	**Tea**
High	High	Plant	Squirrel	**Tree**	Zipper
High	High	Telephone	**Radio**	Peach	Cider
High	High	Student	Raspberry	**Pupil**	Mosquito
High	High	Child	Nun	Pyramid	**Kid**
High	High	Valley	**Hills**	Ant	Wallet
High	High	Road	Volcano	**Street**	Gym
High	High	Bedroom	Eagle	Swamp	**Kitchen**
High	High	Mother	Pickle	Jewel	**Parent**
High	High	Forest	**Woods**	Sunset	Mist
High	High	Window	Ski	**Door**	Sunburn
High	High	River	**Stream**	Bracelet	Helmet
High	High	Sun	Shed	**Moon**	Rabbit
High	High	Money	Alligator	Banana	**Cash**
High	High	Rock	Scissors	Caterpillar	**Stone**
Low	High	Cause	Disclosure	Unreality	**Make**
Low	High	Value	Reciprocal	**Price**	Indifferent
Low	High	Proper	**Appropriate**	Artifice	Mediocrity
Low	High	Reason	Complication	**Explanation**	Chronology
Low	High	Keep	Derivation	Enigma	**Save**
Low	High	Ordinary	**Normal**	Vitriol	Incredulity
Low	High	Advantage	Reformation	Undertaking	**Benefit**
Low	High	Significant	Preference	**Important**	Complication
Low	High	Basic	Emanation	**Simple**	Rarity
Low	High	Constant	**Regular**	Allegory	Debacle
Low	High	Effect	Reprisal	Condescension	**Consequence**
Low	High	Factor	**Part**	Substratum	Gist
Low	High	Average	Temerity	Perpetrator	**Typical**
Low	High	Consider	Equity	**Think**	Misconception
Low	High	Function	**Purpose**	Suffix	Resumption
Low	High	Tendency	**Trend**	Impropriety	Conjugation

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Table A2 (*continued*)

Image	Freq	Target	Response1	Response2	Response3
Med	High	Distance	**Length**	Polka	Gasket
Med	High	Clean	**Wash**	Recess	Benzene
Med	High	Strength	Gasp	**Power**	Blink
Med	High	Ancient	Relic	Molecule	**Old**
Med	High	Fashion	Labyrinth	Molasses	**Style**
Med	High	Religion	Token	**Faith**	Recruit
Med	High	Private	Siege	**Personal**	Oath
Med	High	Society	**Public**	Flora	Rubble
Med	High	Problem	Titbit	**Difficulty**	Riddle
Med	High	Freedom	Canon	**Independence**	Duel
Med	High	Broad	**Wide**	Optimism	Evolution
Med	High	Education	Madness	Dowry	**Teaching**
Med	High	Pair	Carbohydrate	**Couple**	Whiff
Med	High	Property	**Building**	Infinity	Buyer
Med	High	Master	Perch	Sedative	**Professor**
Med	High	Pattern	Tame	Fertile	**Design**
High	Low	Necklace	**Choker**	Dog	Sea
High	Low	Tulip	Car	**Daffodil**	Church
High	Low	Butterfly	Student	Fire	**Moth**
High	Low	Kitten	Plant	Eye	**Gosling**
High	Low	Lobster	**Crayfish**	Square	Doctor
High	Low	Kite	Window	Heart	**Toy**
High	Low	Chestnut	Grass	**Conker**	Artist
High	Low	Shrimp	**Prawn**	University	Road
High	Low	Frog	Bed	**Toad**	Money
High	Low	Ambulance	Ship	Baby	**Lifeboat**
High	Low	Revolver	**Pistol**	Wine	Boat
High	Low	Helmet	Bottle	**Headdress**	Winter
High	Low	Jewel	Neck	**Gem**	Key
High	Low	Zipper	**Fastener**	Summer	Radio
High	Low	Puppy	Clothes	**Kitten**	Knife
High	Low	Violin	Bridge	Horse	**Viola**
Low	Low	Audit	Become	**Inspection**	Put
Low	Low	Protocol	Essential	**Etiquette**	Aware
Low	Low	Alias	Difference	Reason	**Pseudonym**
Low	Low	Arbiter	**Mediator**	Tendency	Condition
Low	Low	Impetus	Determine	Develop	**Motivation**
Low	Low	Despot	Consider	**Tyrant**	Return
Low	Low	Bequest	Influence	Value	**Legacy**
Low	Low	Criterion	**Norm**	Responsibility	Extent
Low	Low	Suffix	Latter	Actual	**Inflection**
Low	Low	Dirge	**Lament**	Considerable	Recent
Low	Low	Deity	Significant	Previous	**Divinity**
Low	Low	Fallacy	Factor	**Myth**	Concept
Low	Low	Interim	**Temporary**	Effect	Purpose
Low	Low	Verity	**Certainty**	Limited	Apparent
Low	Low	Morass	Advantage	**Mire**	Instance
Low	Low	Attribute	Ordinary	Normal	**Trait**
Med	Low	Omen	**Portent**	Send	Pass
Med	Low	Quake	Committee	**Tremor**	Research
Med	Low	Adultery	Sweet	Sharp	**Infidelity**
Med	Low	Wicket	Period	Air	**Pitch**
Med	Low	Enamel	Shelter	Column	**Coating**
Med	Low	Gallant	**Heroic**	Performance	Conference
Med	Low	Emulsion	**Paint**	Law	Service
Med	Low	Expanse	Aid	**Vastness**	Month
Med	Low	Rogue	Health	**Scoundrel**	Scene
Med	Low	Crush	**Squash**	Literature	Temperature
Med	Low	Gentry	**Squire**	Edge	Enemy
Med	Low	Cartilage	Department	Front	**Gristle**
Med	Low	Humour	Master	Childhood	**Wit**
Med	Low	Boredom	Growth	**Dullness**	Design
Med	Low	Hostility	Single	**Aggression**	Strong

Correct responses are shown in bold text.

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