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RESEARCH ARTICLE

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How do valence and meaning interact? The contribution of semantic control

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Abstract

The hub-and-spoke model of semantic cognition proposes that conceptual representations in a heteromodal 'hub' interact with and emerge from modality-specific features or 'spokes', including valence (whether a concept is positive or negative), along with visual and auditory features. As a result, valence congruency might facilitate our ability to link words conceptually. Semantic relatedness may similarly affect explicit judgements about valence. Moreover, conflict between meaning and valence may recruit semantic control processes. Here we tested these predictions using two-alternative forced-choice tasks, in which participants matched a probe word to one of two possible target words, based on either global meaning or valence. Experiment 1 examined timed responses in healthy young adults, while Experiment 2 examined decision accuracy in semantic aphasia patients with impaired controlled semantic retrieval following left hemisphere stroke. Across both experiments, semantically related targets facilitated valence matching, while related distractors impaired performance. Valence congruency was also found to facilitate semantic decision-making. People with semantic aphasia showed impaired valence matching and had particular difficulty when semantically related distractors were presented, suggesting that the selective retrieval of valence information relies on semantic control processes. Taken together, the results are consistent with the hypothesis that automatic access to the global meaning of written words affects the processing of valence, and that the valence of words is also retrieved even when this feature is task-irrelevant, affecting the efficiency of global semantic judgements.

KEYWORDS
aphasia, congruency, semantic, stroke, valence

INTRODUCTION

A representation of PUPPY may rely on knowledge concerning typical visual features and characteristic yapping noises, and that puppies are positive entities who evoke joy. It can be argued that valence (whether items are pleasant or unpleasant) is a core feature of heteromodal concepts. The 'hub-and-spoke' framework suggests that semantic representation relies on interactions between a transmodal hub in the anterior temporal lobes (ATL) and modality-specific spokes; including perceptual and motor features along with valence (Lambon Ralph et al., 2017). Amygdala and orbitofrontal cortex may support the integration of emotion-based features through connections with ATL (Riberto et al., 2019). Patients with semantic dementia (SD), following ATL atrophy, show degradation of conceptual knowledge across tasks that probe the same concepts (Jefferies & Lambon Ralph, 2006), and experience difficulty categorising facial emotions (Lindquist et al., 2014). The ability to make sense of discrete emotions may rely on conceptual representations (Lindquist et al., 2015). Concepts are grounded in valence as well as action and perception (Martin, 2016). Indeed, valence benefits abstract word learning (Ponari et al., 2018) and modulates activation in the anterior cingulate cortex, important for abstract word processing (Vigliocco et al., 2014). Valence can therefore be considered a semantic feature. Conceptual information may modulate the accessibility of valence features and *vice versa*.

Semantic cognition relies not only on heteromodal representations, but also on the ability to flexibly retrieve them; 'semantic control' (Lambon Ralph et al., 2017). Semantic control demands are maximised when meaning is ambiguous and/or there is competition from task-irrelevant information (Jefferies et al., 2019). Neuropsychological studies reveal a double dissociation between degraded conceptual knowledge in SD, and disordered multi-modal semantic control in semantic aphasia (SA) following left frontal-temporal–parietal stroke (Jefferies & Lambon Ralph, 2006). SA patients are sensitive to executive demands of semantic tasks (Jefferies, 2013): They have difficulty retrieving non-dominant conceptual information and are susceptible to semantic distractors (Noonan et al., 2010). This frequently co-occurs with domain-general executive dysfunction (Thompson et al., 2018). SA patients are sensitive to cues that reduce the need to internally constrain retrieval (Noonan et al., 2010). Facial emotions can disambiguate interpretation of words that have both positive and negative meanings in SA (Lanzoni et al., 2019), possibly by modulating semantic control demands and constraining retrieval. SA patients also show deficits in accessing emotions from facial portrayals; common processes may constrain the retrieval of meaning and emotion (Souter et al., 2021).

Neuroimaging research implicates a distributed but largely left-lateralised 'semantic control network' (SCN) in semantic retrieval, which includes anterior left inferior frontal gyrus (IFG) and posterior middle temporal gyrus (pMTG; Jackson, 2021). These regions are adjacent to domain-general control regions (Gao et al., 2021). Lesion to and structural disconnection between left-hemisphere SCN regions predicts semantic control deficits in SA (Souter, Wang, et al., 2022). Regions of SCN are also implicated in tasks involving valence—including comparisons of lexical decision for valenced versus neutral words (Pauligk et al., 2019) and the resolution of conflict from valence incongruency (Gao et al., 2020). SCN may play a role in controlling the retrieval of emotion along with other aspects of meaning.

Semantic control may be required to match words by valence when they do not share other features (PUPPY and CAKE both have positive valence but no semantic link), since a single task-relevant feature must compete with many irrelevant features. This has been reported for colour (Thompson-Schill et al., 1997).

Global semantic similarity facilitates feature matching, reducing SCN activation (Wang et al., 2020). Global similarity refers to the similarity of contexts in which words are used, and should be sensitive to shared features and strength of thematic association. If access to valence irrespective of global similarity requires semantic control, patients with SA should be impaired at valence matching. Furthermore, a mismatch in valence may make it harder to identify global links between words. This effect, based on a single task-irrelevant feature, should be smaller than the effect of global semantic similarity on valence matching. Valence congruency between words facilitates healthy adults' detection of global semantic relationships, particularly for weak associations (Marino Dávolos et al., 2020). This may be magnified in SA due to difficulty resolving competition from valence. Here, we investigated effects of (i) semantic relatedness on the ability to match words by valence and (ii) valence congruency on the ability to match words by semantic relatedness. In Experiment 1, we studied healthy young adults, asked to respond as fast and accurately as possible. In Experiment 2, we observed SA patients and age-matched controls to establish if these effects are magnified by semantic control deficits.

EXPERIMENTAL PARADIGM

Stimuli

Stimuli were nouns taken from a database (Warriner et al., 2013) which reports mean valence and arousal of words on a scale from 1 to 9, using participant ratings. We classified words above 6 as positively valenced, between 4 and 6 as neutral, and below 4 as negative.[1] We excluded words with a standard deviation of valence ratings above 2, which may have ambiguous meaning (e.g., 'jam') or diverse emotional reactions (e.g., 'religion'). We assessed the strength of association between each probe-target and probe-foil pair using word2vec (Mikolov et al., 2013), a measure of semantic distance between words based on co-occurrence in text and an effective proxy for semantic relatedness (Pereira et al., 2016). Other approaches are available, such as asking participants to self-generate associations. Co-occurrence was the most practical way of measuring semantic relatedness while balancing psycholinguistic properties. An association was considered 'strong' if word2vec was above .2, 'weak' if between .1 and .2, and negligible if below .1. Stimuli were controlled for valence, strength of association, word frequency, and psycholinguistic factors (see Supporting Information section 'Stimulus Properties'). Negative words were significantly higher in arousal than positive words. To observe for potential effects of this confound, each mixed effects model used in this study was re-run with arousal congruency between probe and target word as a predictor (see Table S2). No effect of arousal congruency was found in any model, nor did its inclusion attenuate any other effects. It is therefore likely that observed effects of valence congruency can be attributed to valence itself, rather than arousal.

Valence matching task

The valence matching task required participants to match one of two words to a probe word by valence. The target was always the same valence as the probe, while the foil was the opposite valence. Participants were told: "your task is to indicate which of the two words on the bottom has the same emotional valence (positive or negative) as the word on the top". We manipulated strength of semantic association. In the *associated target* condition, the probe had a strong association with the target and no association with the foil. In the *no association* condition, the probe had no association with either response option. In the *associated distractor* condition, the probe had no association with the target but a strong association with the foil. It was predicted that the *associated target* condition would facilitate valence matching through

[1]Valenced words included largely emotion-laden terms with acquired affective connotation (e.g., war, rainbow). 9.5% of stimuli could be considered emotion-label, representing affective states (e.g., hope, terror).

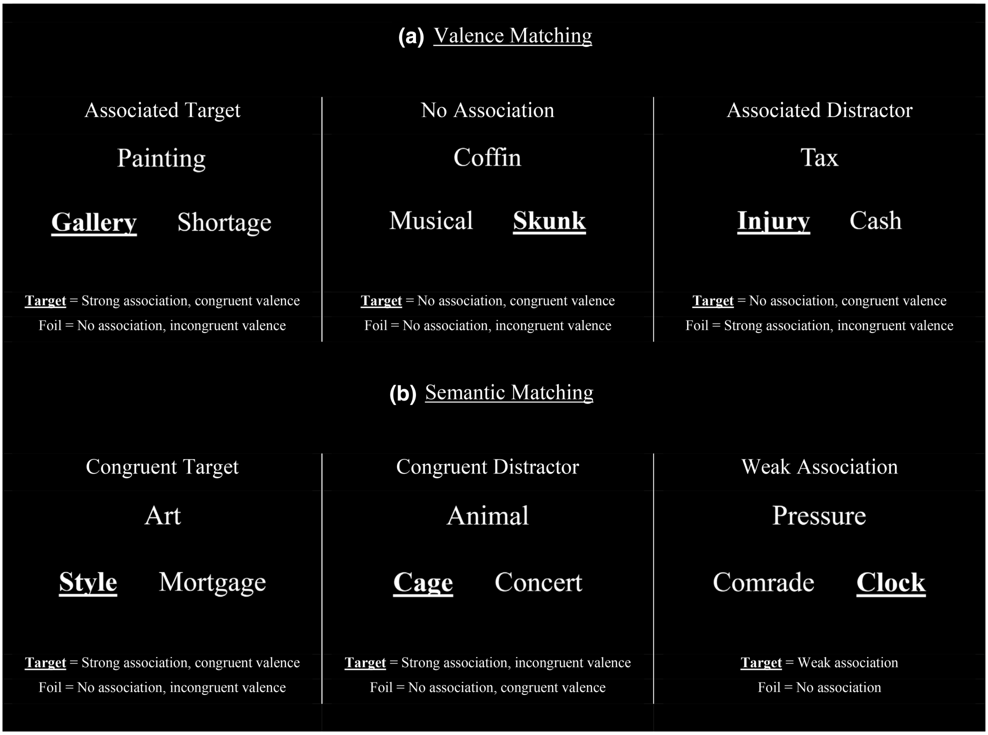


FIGURE 1 Examples of trials in each condition in the (a) valence matching and (b) semantic matching tasks. The relationship to the probe word for both the target and foil is explained for each example. Target words are underlined and in bold.

semantic cueing, while the *associated distractor* condition would impair matching by requiring inhibition of the distractor. Example trials can be seen in Figure 1a.

Semantic matching task

The semantic matching task required participants to match one of two words to a probe by semantic relatedness. Participants were told: "your task is to indicate which of the two words on the bottom has the strongest connection to the word on top". Two conditions manipulated valence congruency, a third manipulated association strength. In the *congruent target* condition, the target had a strong association to the probe and was congruent in valence, while the foil had no association and was incongruent. In the *congruent distractor* condition, the target had a strong association to the probe but was incongruent in valence, while the foil had no association but was congruent. In the *weak association* condition, the target had a weak association to the probe, while the foil had no association. Valence congruency was not manipulated here due to challenges sourcing weakly associated targets while manipulating valence. The valence of the foil was congruent with the probe in half of the trials, and incongruent in the remainder. Example trials can be seen in Figure 1b.

Trial structure

The experiment was split across two sessions separated by at least a week, each containing a block of valence matching and of semantic matching. Trial order was randomised within blocks. The same response triads were used across (i) 'valence – associated target' and 'semantic – congruent target' and (ii) 'valence – associated distractor' and 'semantic – congruent distractor' (target response switched). Triads in the 'valence – no association' condition were re-used in the 'semantic – weak association' condition, with one response option replaced with a weakly associated target. Presentation order was counterbalanced, such that if a given triad appeared in valence matching in session 1, it appeared in semantic matching in session 2. Target responses appeared on the left in half of the trials, and on the right in the remainder. Each condition contained 27 trials, providing 81 trials per task, and 162 trials overall.

EXPERIMENT 1: YOUNG ADULTS

Method

Participants

Participants were neurologically healthy adults tested on the online platform Gorilla (www.gorilla.sc; Anwyl-Irvine et al., 2020). Eighty-six participants were recruited opportunistically. Participants automatically received an email one week after the first session, prompting them to complete the second. Participants were excluded if they did not complete the second session ($N = 11$), if they scored below chance (50% accuracy) on any condition ($N = 14$), or if their median response time for any condition was an outlier ($N = 3$), as determined in SPSS (version 27.0; IBM Corp., 2020). The sample consisted of 60 adults (38 female) between the ages of 19 and 41 [Mean (SD) = 25.1 (5.6)].

Design

A within-subjects design was used; all participants completed both the valence matching and semantic matching tasks.

Procedure

Block order (valence/semantic) was randomised within each session. At the start of each block participants saw instructions explaining the matching strategy and an example trial with explanation of the correct answer. Valence matching instructions did not disclose that association strength would be manipulated, and semantic matching instructions did not disclose that valence congruency or association strength would be manipulated. Participants were instructed to press the '1' key on their keyboard to select the left response option, and '2' to select the right option. Before each block, participants completed six practice trials including feedback. Between blocks, participants saw a warning of the change in task instructions. No time limit was applied.

Data analysis

For each condition we extracted each participant's accuracy (percent correct) and response time (RT; seconds) for correct responses. Median RT, rather than mean RT, was extracted for each condition at the individual-level to reduce effects of outliers. At the group-level, the mean of median RTs for each condition was assessed. We entered accuracy and RT on all conditions into separate principal components analyses (PCA) with varimax rotation, to assess whether performance across conditions loads onto common components.

To assess the effect of semantic association on valence matching, we conducted one-way repeated measures ANOVAs, comparing accuracy and RT across the three conditions.

Effects of valence congruency on semantic matching were assessed by comparing performance across the *congruent target* and *congruent distractor* conditions with Wilcoxon signed-rank tests since the normality assumption was violated. We then assessed the effect of association strength by averaging across the *congruent target* and *congruent distractor* conditions to produce a *strong association* score, which was compared to the *weak association* condition using Wilcoxon signed-rank tests. This *strong association* score should control for valence, as trials are equally split across congruent targets and foils. While target valence congruency was not manipulated for *weak association* trials, the foil was congruent in half trials.

Given evidence that valence congruency effects depend on association strength (Marino Dávolos et al., 2020), we examined the parametric effect of probe-target association strength (using word2vec) across the *congruent target* and *congruent distractor* conditions. For accuracy, we used a mixed effects logistic regression, predicting the probability of a correct response. For RT, a mixed effects linear regression was used. Outliers were addressed by removing RTs larger than either 10 s or 3 standard deviations above a given participant's mean RT in each condition. RTs were log transformed such that residuals were approximately normally distributed. Condition and association strength were used as fixed factors, and participant identity and item (trial) as crossed random factors. Likelihood ratio tests were used to determine significance by statistically comparing the full model to nested versions with effects or interactions removed, using the chi-square distribution. We used the same method to assess effects of association strength on valence matching – restricted to the *no association* and *associated distractor* conditions, given that target strength was matched across them. This observes effects of semantically associated distractors on valence matching as a function of association strength but does not provide insight into the relationship between valence congruency and processing of meaning. This is reported in the Supporting Information section 'Valence Congruency Mixed Effects Models – Experiment 1'.

Finally, we performed two-way repeated measures ANOVA with variables of task (valence matching vs. semantic matching) and difficulty (easy ['valence – associated target' and 'semantic – congruent target'] vs. hard ['valence – associated distractor' and 'semantic – congruent distractor']). This allowed us to compare performance across tasks and assess whether either difficulty manipulation was more influential.

Results

Participants' mean accuracy and RT in each condition are in Figure 2.

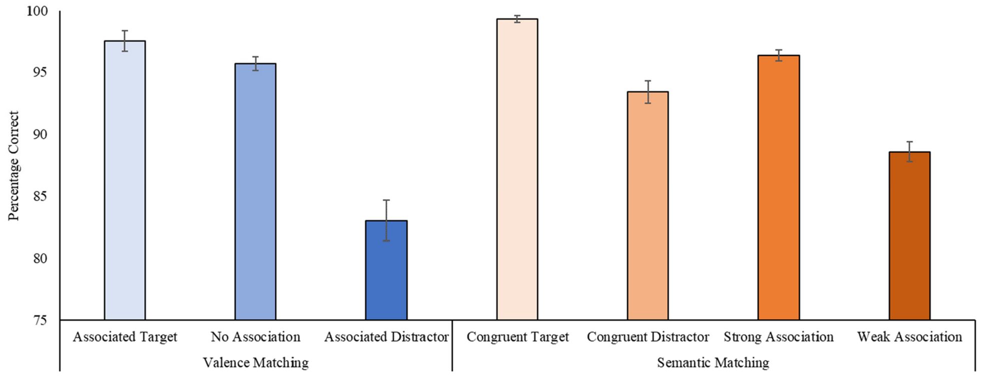
Principal components analysis

PCA revealed two components for accuracy and one for RT (see Table 1).

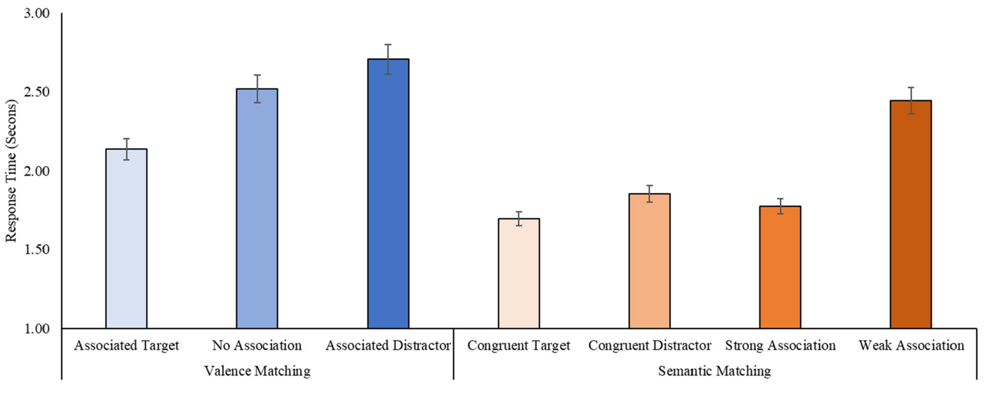
The first accuracy component appears to reflect conditions which should be automatic; valence matching without semantically associated distractors and semantic matching with valence-congruent targets. The second component appears to reflect conditions which should require controlled processing; valence matching with associated distractors, semantic matching with valence-incongruent targets, and weak associations. The RT factor suggests that faster responses on a given condition are associated with faster responses on all other conditions. Alternative interpretations are possible.

Valence matching

Repeated measures ANOVAs were used to examine performance across the valence matching conditions. We found significant effects of condition for accuracy [$F(1.3, 73.9) = 55.0$, $p < .001$, $\eta_p^2 = .48$] and RT [$F(2, 118) = 38.2$, $p < .001$, $\eta_p^2 = .39$]. Post-hoc contrasts (Bonferroni-corrected for two comparisons for each ANOVA) revealed significant differences between the *associated target* and *no association* conditions



(a) – Accuracy



(b) – Response Time

FIGURE 2 Participants' (a) mean accuracy (percentage correct) and (b) mean response time (seconds) for each task and condition in Experiment 1. Error bars reflect one standard error of the mean. The 'Strong Association' bars reflect the average of performance on the 'Congruent Target' and 'Congruent Distractor' conditions.

TABLE 1 Rotated component matrices for principal components analysis of Experiment 1 with varimax rotation, examining accuracy and response time across conditions.

		Accuracy		Response time
Matching task	Condition	Component 1 (Eigenvalue = 1.83)	Component 2 (Eigenvalue = 1.73)	Component 1 (Eigenvalue = 4.65)
Valence	Associated target	**.772**	−.206	**.845**
	No association	**.806**	.099	**.871**
	Associated distractor	.149	**.701**	**.836**
Semantic	Congruent target	**.705**	.122	**.903**
	Congruent distractor	−.129	**.716**	**.913**
	Weak association	.032	**.841**	**.908**

Note: Strong loadings for each component in bold.

[accuracy: $t(59) = 2.4$, $p = .039$, RT: $t(59) = -5.9$, $p < .001$] and between the *no association* and *associated distractor* conditions [accuracy: $t(59) = 7.8$, $p < .001$, RT: $t(59) = -2.9$, $p = .009$].[2] This suggests that semantically related targets facilitated valence matching, while distractors impaired performance.

Semantic matching

Next, we contrasted performance on the semantic matching conditions that involved targets and distractors of the same valence, and that involved strong and weak associations. The two comparisons for both accuracy and RT were Bonferroni-corrected. For both measures, there was a significant difference between the *congruent target* and *congruent distractor* conditions [accuracy: $Z = -5.5$, $p < .001$,[3] RT: $Z = -4.5$, $p < .001$], and between *strong association* and *weak association* trials [accuracy: $Z = -6.4$, $p < .001$, RT: $Z = -6.7$, $p < .001$]. This suggests that valence-congruent targets facilitated semantic decisions relative to trials with valence-congruent distractors, and that weak associations conferred greater semantic control demands than strong associations (see Figure 2).

The semantic task involved separate manipulations of valence congruency and association strength. To establish if these factors interact, we used mixed effects models. Valence congruency was included as a binary predictor (*congruent target* vs. *congruent distractor*), while association strength was continuous (word2vec score between target and probe word). Participant identity and item (trial) were used as crossed random factors. Results can be seen in Table 2.

Stronger probe-target association predicted more accurate and faster responses, while valence congruency predicted faster responses. Valence congruency did not affect accuracy, contrary to the Wilcoxon test reported above. This effect may be attenuated when factoring in random variation attributable to test item. For both measures, a significant interaction was found. These interactions were parsed using the emtrends function of the emmeans package (Lenth, 2020), and visualised using the ggpredict function of the ggeffects package (Lüdecke, 2018); see Figure 3.[4] For the *congruent target* condition, greater association strength was associated with a higher probability of a correct response and faster responses [accuracy: association = 6.07, LCL = 4.16, UCL = 7.99, RT: association = −.77, LCL = −.93, UCL = −.61]. For the

TABLE 2 Output of Experiment 1 semantic matching mixed effects regressions.

Measure	Variable	Estimate	Lower 95% CI	Upper 95% CI	Likelihood ratio test
Accuracy	Intercept	2.49	2.04	2.94	–
	Valence congruency	1.28	−.51	3.08	$\chi(1) = 1.94$, $p = .163$
	Association strength	**6.07**	**4.16**	**7.99**	**$\chi(1) = 37.69$, $p < .001$***
	Valence by strength	**−6.54**	**−11.6**	**−1.43**	**$\chi(1) = 6.10$, $p = .014$***
Response time	Intercept	.97	.91	1.04	–
	Valence congruency	**−.37**	**−.54**	**−.20**	**$\chi(1) = 17.39$, $p < .001$***
	Association strength	**−.77**	**−.93**	**−.61**	**$\chi(1) = 71.23$, $p < .001$***
	Valence by strength	**.88**	**.40**	**1.36**	**$\chi(1) = 12.62$, $p < .001$***

Note: *Reflects a significant result. Significant results are also presented in bold. The Accuracy model was run in R using lme4 package (version 1.1-25; Bates et al., 2015). As this is a logistic model, estimate coefficients reflect log transformation of odds ratios (Larsen et al., 2000). The Response Time model was run in R using lmerTest package (version 3.1-3; Kuznetsova et al., 2017), response time values are log transformed.

Abbreviation: CI, confidence interval.

[2]The assumption of normality was not always met but non-parametric tests elicited the same outcomes. Accuracy: *associated target – no association* [$Z = -3.0$, $p = .005$], *no association – associated distractor* [$Z = -5.9$, $p < .001$]. RT: *associated target – no association* [$Z = -4.9$, $p < .001$], *no association – associated distractor* [$Z = -3.6$, $p < .001$].

[3]Note that this effect is not significant in the mixed effects model below.

[4]Although RT was estimated using a linear mixed effects model, trends visualised are curved as RT was log-transformed. Similarly, accuracy was estimated using log transformation of odds ratios.

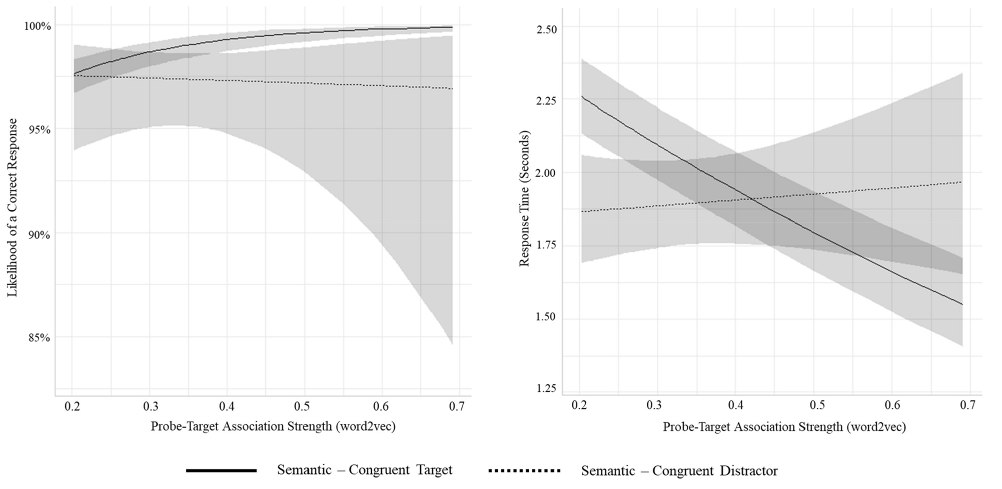


FIGURE 3 Associations between probe-target association strength and both the likelihood of a correct response (left) and response time (right) for the Experiment 1 semantic matching task. Grey shaded areas reflect confidence intervals based on the standard errors.

TABLE 3 Experiment 1 task comparison ANOVA results.

Measure	Effect	Result
Accuracy	**Task**	F (1, 59) = 45.1, $p < .001$, $\eta_p^2 = .43$*
	Difficulty	F (1, 59) = 79.7, $p < .001$, $\eta_p^2 = .58$*
	Task by difficulty	F (1, 59) = 20.4, $p < .001$, $\eta_p^2 = .26$*
Response Time	**Task**	F (1, 59) = 201.1, $p < .001$, $\eta_p^2 = .77$*
	Difficulty	F (1, 59) = 72.7, $p < .001$, $\eta_p^2 = .55$*
	Task by difficulty	F (1, 59) = 36.6, $p < .001$, $\eta_p^2 = .38$*

Note: *Reflects a significant effect.

congruent distractor condition, no effect of association strength was observed [accuracy: association = −.47, LCL = −5.20, UCL = 4.27, RT: association = .11, LCL = −.34, UCL = .56]. This suggests that benefits of association strength may not occur when participants must resolve inconsistency between valence and meaning. Stronger associations appear more advantageous when incongruency is not present.

Task comparison

We compared the effect of congruency/relatedness across tasks using repeated-measures ANOVA. Results are in Table 3. There were significant effects of task and difficulty and a significant task by difficulty interaction for both accuracy and RT. This reflects more accurate and faster responses for semantic matching than valence matching, and for congruent/related than incongruent/distractor trials. The interactions reflect larger effects of semantic relatedness on valence matching than of valence congruency on semantic matching (see Figure 2), as expected as valence is only one of many semantic features.

EXPERIMENT 2: SEMANTIC APHASIA PATIENTS

Experiment 2 employed the same tasks, with SA patients and age-matched controls.

Method

Participants

Participants included five patients and 15 neurologically healthy controls. All patients had left hemisphere stroke. They had an average age of 61.5 (*SD* = 6.3), average age of leaving education of 19.8 (*SD* = 3.6), and an average of 13.6 years (*SD* = 5.0) since stroke. Controls had an average age of 65.0 (*SD* = 6.7) and average age of leaving education of 21.2 (*SD* = 3.0). Patients were selected from a database of SA patients who were recruited from communication support groups across Yorkshire. Patients in the current sample were those able to engage with remote testing due to restrictions during the COVID-19 pandemic. Information on lesion location, when available, is reported in the Supporting Information section 'Lesion Analysis' and displayed in Figure S3.

Background neuropsychological testing

Patients were tested on language, memory, visuospatial processing, executive function, and semantic cognition. Description of patients' performance on specific assessments can be seen in the Supporting Information section 'Background Neuropsychology'. Individual patients' performance on non-semantic and semantic assessments is in Tables S5 and S6, respectively. Patients showed minimal impairment in word repetition, but all showed impaired verbal fluency. Four had impaired verbal working memory. All had preserved visuospatial processing. Two were impaired on at least one test of executive function.

On the Cambridge Semantic Battery (Bozeat et al., 2000), patients showed variable performance on picture naming, but invariably improved following phonemic cueing. Patients performed near ceiling on word-picture matching and showed at least some impairment on picture and word versions of the associative Camel and Cactus Test. All showed impairment on assessments which manipulated semantic control: including difficulty retrieving subordinate thematic associations, deleterious effects of semantic distractors, and benefits of contextual cueing. Given relatively preserved performance on aspects of the Cambridge Semantic Battery, patients should be conceptualised as presenting with impairments in semantic control, rather than deficits in semantic representation as in SD (Jefferies & Lambon Ralph, 2006). All patients were impaired on at least one verbal and non-verbal measure of semantic control, consistent with Jefferies and Lambon Ralph (2006), although the current sample may have relatively mild impairment due to the use of demanding semantic tasks. Our sample is also consistent with the original definition of SA as impairment in the flexible manipulation of information for abstract and symbolic processing (Head, 1926). Patients' deficits extend beyond those reported by Head (1926), with added evidence of impaired language, working memory, and executive function. Patients were not excluded based on impairments beyond the semantic domain. Patients were grouped based on the presence of shared semantic control impairments, as in prior studies (Stampacchia et al., 2018). Using this group, we can ask whether semantic control impairments in SA extend to valence matching, but cannot rule out the contribution of non-semantic impairments.

Patients' degree of semantic control impairment was quantified using the results of PCA previously conducted on a larger sample (*N* = 17, including the current five; Souter, Stampacchia, et al., 2022). Regression scores were taken as patients' semantic control composite scores. These can be seen in Table S6. Loadings for this component are in Table S7.

Design

We used a mixed design, with patients and controls completing both the valence matching and semantic matching tasks.

Procedure

The paradigm was coded in PsychoPy3 (Peirce et al., 2019) and run remotely over Zoom (Zoom Video Communications Inc., 2016). The researcher shared their screen such that the participant could see the experiment, and gave them remote control of the cursor. At the start of each session, participants were shown instructions and practice trials as in Experiment 1 (see Procedure Section). To respond, participants moved the cursor over the response they wished to select. The researcher then recorded their choice by pressing a button – an analogue to pointing at the screen, the method typically employed during our in-person testing.

Data analysis

Accuracy (percent correct) was the dependent measure. Each patient was classified as either impaired or not impaired on each condition using Singlims (Crawford et al., 2010), which compares an individual score to the respective control mean and standard deviation. One-tailed p-values below .05 were taken as reflecting impairment.

As sample size was insufficient to run ANOVAs as in Experiment 1, we used mixed effects logistic regressions in R (R Core Team, 2020). All models were fit by maximum likelihood, based on Gaussian Hermite approximation, and run using the lme4 package (version 1.1-25; Bates et al., 2015). Models predicted the likelihood of a correct response for a given trial under varying conditions and included participant identity and item as random factors. Likelihood ratio tests determined the contribution of specific effects and interactions, by statistically comparing full models to nested versions with the respective effect removed, using the chi-square distribution.

Four models were created. (1) A 'valence matching' model restricted to the valence matching task used group (patients vs. controls), condition (*associated target* vs. *no association* vs. *associated distractor*), and their interaction as fixed effects. (2) A 'semantic matching (binary)' model restricted to the semantic matching task used group (patients vs. controls), binary association strength (*strong association* vs. *weak association*), and their interaction as fixed effects. As in Experiment 1, *strong association* trials were comprised of both *congruent target* and *congruent distractor* trials. (3) This was followed by a 'semantic matching (parametric)' model, which allowed us to consider the interaction between valence congruency (*congruent target* vs. *congruent distractor*) and parametric probe-target association strength (using word2vec scores), across groups (patients vs. controls).[5] (4) Finally, a 'task comparison' model included group (patients vs. controls), task (valence vs. semantic), and difficulty (easy ['valence – associated target' and 'semantic – congruent target'] vs. hard ['valence – associated distractor' and 'semantic – congruent distractor']) as fixed effects. Each possible interaction was included. When necessary, interactions were followed by post-hoc contrasts in emmeans (Lenth, 2020), which quantify differences based on odds ratios (OR), with Bonferroni correction applied.

Results

Impairment of individual patients assessed with Singlims

Each patient's percentage accuracy for each condition, and average accuracy for patients and controls, can be seen in Figure 4. Conditions on which patients were impaired, determined in Singlims, are reflected by asterisks. In the valence matching task, patients performed near ceiling on the *associated target* condition, with none impaired. Two patients were impaired on the *no association* condition. Three were impaired on

[5]As in Experiment 1, we used the same method to assess the effect of association strength on valence matching – restricted to the *no association* and *associated distractor* conditions. This analysis is reported in the Supporting Information section 'Valence Congruency Mixed Effects Models – Experiment 2'.

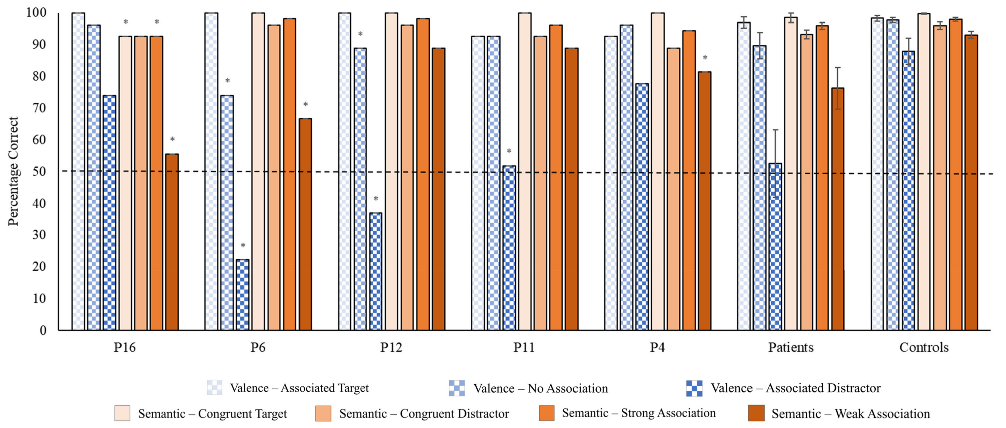


FIGURE 4 Percentage correct for each condition in the valence and semantic matching tasks for each patient and for the average of the patient and controls groups. *Reflects impairment relative to controls based on Singlims analysis. The dotted line reflects chance level performance (50%). Error bars reflect one standard error of the mean. Patients are ordered left to right in descending order of semantic control impairment, on the basis of their semantic control composite score.

the *associated distractor* condition, performing at or below chance-level. In the semantic matching task, patients generally performed near ceiling on the *congruent target* condition, with only one impaired. None were impaired on the *congruent distractor* condition. Only one was impaired on *strong association* trials (the confluence of *congruent target* and *congruent distractor*). Three patients were impaired on the *weak association* condition, with one performing close to chance.

Group comparison mixed effects models

Experiment 2 mixed effects logistic regressions are in Table 4.

Valence matching

The valence matching model revealed significant effects of group and condition, and a group by condition interaction. The effect of group reflected higher accuracy in controls than patients. To parse the interaction, contrasts in emmeans compared performance on each condition between groups. While no difference was found for the *associated target* condition (OR = .48, $p > 1$), controls were more likely than patients to produce a correct response in the *no association* (OR = .13, $p = .002$) and *associated distractor* (OR = .08, $p < .001$) conditions. This suggests impaired valence matching in patients, most notable in the presence of related distractors, that is ameliorated by related targets. When running within-group contrasts (Table S8), both groups show reduced accuracy following associated distractors, relative to baseline. Neither sees a significant improvement from associated targets. While patients do not benefit from related targets in absolute terms, this is the only condition on which they do not present with impairment relative to controls.

Semantic matching (binary)

The first semantic matching model observed for binary effects of association strength. Again, controls were more likely to produce a correct response than patients. There was also a significant effect of association strength, reflecting higher accuracy on *strong association* than *weak association* trials. Finally, a significant group by association strength interaction reflects that patients were disproportionately impaired by weak associations (see Figure 4).

TABLE 4 Output of Experiment 2 mixed effects logistic regressions.

Model	Variable	Estimate	Lower 95% CI	Upper 95% CI	Likelihood ratio test
Valence matching	Intercept	3.08	2.27	3.88	–
	Group	**1.64**	**.80**	**2.49**	**$\chi(1) = 11.9, p = .001$***
	Condition	**–**	**–**	**–**	**$\chi(2) = 57.0, p < .001$***
	Group by condition	**–**	**–**	**–**	**$\chi(2) = 9.60, p = .008$***
Semantic matching (binary)	Intercept	3.91	3.04	4.78	–
	Group	**1.32**	**.41**	**2.24**	**$\chi(1) = 7.44, p = .006$***
	Association strength	**−3.07**	**−3.84**	**−2.31**	**$\chi(1) = 69.5, p < .001$***
	Group by association strength	**.90**	**.21**	**1.58**	**$\chi(1) = 6.53, p = .011$***
Semantic matching (parametric)	Intercept	.80	−.05	1.66	–
	Group	**2.38**	**1.49**	**3.26**	**$\chi(1) = 19.2, p < .001$***
	Valence congruency	**4.15**	**1.07**	**7.23**	**$\chi(1) = 7.09, p = .008$***
	Probe-Target association	**10.12**	**6.70**	**13.54**	**$\chi(1) = 42.9, p < .001$***
	Group by congruency	−1.27	−4.05	1.50	$\chi(1) = .79, p = .374$
	Group by association	−2.93	−6.36	.51	$\chi(1) = 2.79, p = .095$
	Valence congruency by association	**−13.22**	**−21.73**	**−4.71**	**$\chi(1) = 8.33, p = .004$***
	Group by association by congruency	2.18	−5.50	9.86	$\chi(1) = .30, p = .584$
Task comparison	Intercept	2.81	1.91	3.72	–
	Group	**1.80**	**.87**	**2.73**	**$\chi(1) = 12.4, p < .001$***
	Task	.80	−.14	1.74	$\chi(1) = 2.82, p = .093$
	Difficulty	.98	−.22	2.18	$\chi(1) = 2.65, p = .104$
	Group by task	−.20	−1.15	.75	$\chi(1) = .17, p = .682$
	Group by difficulty	−.98	−2.10	.14	$\chi(1) = 3.00, p = .083$
	Task by difficulty	**−4.44**	**−6.03**	**−2.85**	**$\chi(1) = 32.1, p < .001$***
	Group by task by difficulty	**1.89**	**.44**	**3.34**	**$\chi(1) = 6.58, p = .010$***

Note: *Reflects significance at the .05 threshold. Significant results are also presented in bold. Models were run in R using lme4 package (version 1.1-25; Bates et al., 2015). As these are logistic models, estimate coefficients reflect log transformation of odds ratios (Larsen et al., 2000). The valence matching condition effect and group by condition interaction do not include an estimate value, as these effects are not provided by the overall model. The respective likelihood ratio test results were obtained by comparing the full model to nested versions in which all condition main effects or interactions were removed.

Abbreviation: CI, confidence interval.

Semantic matching (parametric)

The second semantic matching model looked for parametric effects of association strength, and interactions with group and valence congruency. Controls were more likely to produce a correct response than patients. We observed an effect of valence congruency, reflecting higher accuracy in the *congruent target* than *congruent distractor* condition (see Figure 4). We observed a significant effect of probe-target association strength, and an interaction between strength and valence congruency. This interaction was parsed using the emtrends function of the emmeans package (Lenth, 2020), and visualised using the ggpredict function of the ggeffects package (Lüdecke, 2018; Figure 5). Across groups, a positive effect of association strength on accuracy was found for the *congruent target* condition (association = 8.66, LCL = 5.79, UCL = 11.52). In the *congruent distractor* condition, no effect was observed (association = −3.48, LCL = −9.89, UCL = 2.94).

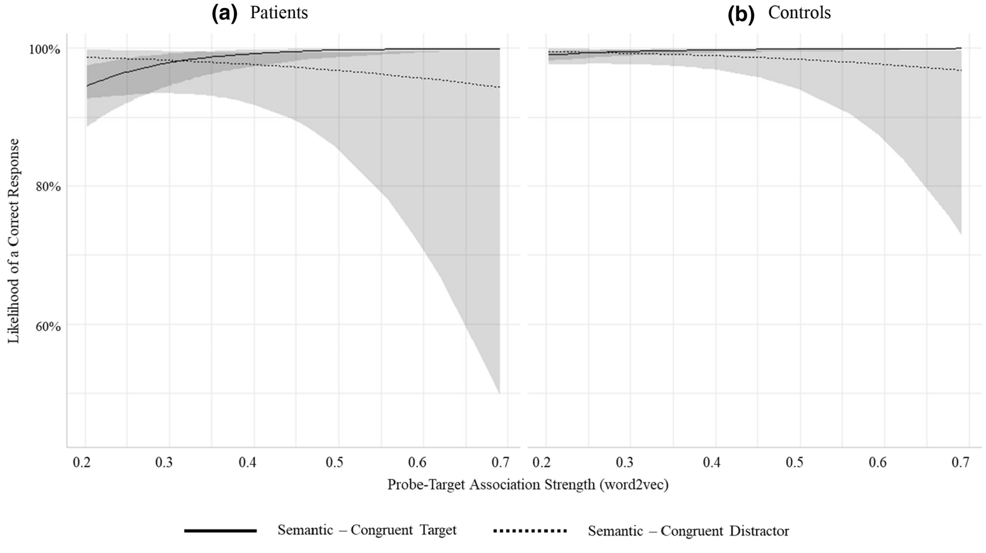


FIGURE 5 Associations between probe-target association strength and the likelihood of a correct response for the Experiment 2 semantic matching task in (a) semantic aphasia patients and (b) control participants. Grey shaded areas reflect confidence intervals based on the standard errors.

Task comparison

A significant effect of group reflected that controls were more likely to provide correct responses than patients. There was a task by difficulty interaction, and a group by task by difficulty interaction. As reported in the Valence matching Section, patients were less likely to produce a correct response than controls for *valence – associated distractor* trials but not for *valence – associated target* trials. No group differences were observed for *semantic – congruent target* (OR = .13, p = .469), or *semantic – congruent distractor* trials (OR = .45, p = .746). Effects of semantic relatedness on valence matching were larger than effects of valence congruency on semantic matching, particularly for patients (see Figure 4). This might reflect difficulty selecting goal-relevant features when semantic control demands are high.

DISCUSSION

The hub-and-spoke model implicates valence as a feature of semantic concepts (Lambon Ralph et al., 2017), supported by research into abstract word processing (Ponari et al., 2018; Vigliocco et al., 2014). Accordingly, valence may influence judgements of semantic relatedness. Due to modulation of semantic control demands, global semantic similarity may influence ability to match words by valence. Such effects may be exaggerated in SA patients with impairments in constraining internal information. In young adults with a sensitive measure of RT (Experiment 1) and in five left-hemisphere stroke patients with SA and age-matched controls (Experiment 2), we found evidence that (i) accessing word valence is vulnerable to interference from overall meaning; (ii) valence congruency can facilitate access to word meaning, (iii) effects of semantic relatedness on valence matching are larger than effects of valence congruency on semantic matching, and (iv) effects of semantic distractors on valence matching are increased in SA. We further demonstrated that in the context of strong semantic associations, parametric increases in probe-target association strength facilitate responses only when words are congruent in valence. Finally, participants were more accurate and faster when retrieving strong than weak semantic associations – heightened in SA.

Valence can be considered a semantic feature, as concepts are grounded in valence as they are for action and perception (Martin, 2016). A distinction can be made between 'affective' valence; experiencing something as negative – and 'semantic' valence; knowing something is negative (Itkes & Kron, 2019). One may understand that a flower is a positive entity without deriving joy. This distinction may be related to the separation between emotion-laden words that are imbued with affective connotations, and emotion-label words that convey affective states (Zhang et al., 2017). Only 9.5% of words across conditions were emotion-label, meaning terms were largely emotion-laden. While we had insufficient emotion-label stimuli to explore differential effects of these categories on semantic matching, future researchers may wish to test this distinction. The intersection of valence and meaning is consistent with theory that perception of discrete emotions relies on semantic knowledge (Lindquist et al., 2015). Indeed, this ability is impaired following deficits in semantic storage (Lindquist et al., 2014) and control (Souter et al., 2021). Matching words by valence may require participants to focus on a specific feature while disregarding others that together determine global similarity. This may account for why valence matching was impaired by related distractors; this requires inhibition of task-irrelevant features. Accordingly, SA patients were disproportionately affected by this manipulation. SA patients were frequently impaired on valence matching even in the absence of distractors. Patients were not impaired relative to controls in the context of semantically related targets, suggesting facilitatory effects of global relatedness in accessing concept valence. The observed effects of cueing and miscueing in SA are consistent with prior evidence (Noonan et al., 2010). The current findings suggest an important role of valence in the lexicon, such that it may facilitate access to other featural and contextual aspects of concepts.

Due to dominance of global relatedness over specific features (Thompson-Schill et al., 1997), effects of valence on semantic judgements were predicted to be modest. Nevertheless, we saw improved semantic matching in the context of valence-congruency. This is consistent with prior evidence of facilitatory effects of valence congruency on semantic matching (Marino Dávolos et al., 2020). Due to the design employed, we could not replicate previous analysis from Marino Dávolos et al. (2020), demonstrating that valence congruency is particularly helpful for retrieving weak associations. Valence congruency was only manipulated for strongly associated word pairs. We instead looked for effects of parametric probe-target association strength under conditions of valence-congruency and incongruency. Greater association strength facilitated semantic matching when the probe and target were congruent in valence, but not when they were incongruent. Benefits of stronger associations were reduced when participants needed to resolve valence incongruency between the probe and target, while disregarding valence-congruent distractors. Given the results of Marino Dávolos et al. (2020), we might expect this interaction to take a different form when weaker associations are presented, reflecting the changing contribution of decisional uncertainty and controlled retrieval demands as task parameters vary.

Current findings suggest that access to valence is susceptible to control demands. Indeed, PCA in Experiment 1 suggests that accuracy on conditions that were more automatic or control-demanding loaded onto separate factors, regardless of task (semantic vs. valence). The involvement of control in valence processing is highlighted by evidence that divided attention can disrupt emotion-enhanced memory effects of valenced stimuli (Kang et al., 2014). Specific neural substrates may support controlled processing of valence. Zhuang et al. (2021) compared neural activation during tasks requiring domain-general response inhibition to those involving the manipulation of emotional context. Lateral frontal regions were engaged regardless, while the ventral striatum and medial orbitofrontal cortex were sensitive to emotional context. Similarly, SCN regions including bilateral IFG and left pMTG (Jackson, 2021) are reliably activated for tasks requiring reappraisal of valenced stimuli (Messina et al., 2015). Messina et al. (2015) argue for contributions of semantic processing and executive control to emotion reappraisal, due to the need to access alternative representations of affective stimuli. SCN has been argued to allow for the integration of long-term abstract memory representations with goal states (Wang et al., 2020). This network, damaged in SA (Souter, Wang, et al., 2022), may support the control of both meaning and emotion.

Limitations

Due to social distancing restrictions during the COVID-19 pandemic, Experiment 2 was conducted remotely. The demands of this method (e.g., self-directed computer use) led to the exclusion of more impaired patients from our database, reducing our sample size. For the same reason, it was not possible to obtain neuroanatomical scans for all patients, preventing us from relating behavioural impairment with lesion profile. We saw evidence of individual-level task impairments, determined by Singlims. These impairments were not consistent across all patients. Further work with larger groups may be helpful in confirming our observations. We saw group-level differences in mixed effects models while controlling for random variation attributable to participant identity, suggesting meaningful group differences. Despite this, this small sample size limits out ability to predict whether effects would generalise to other patients with this symptom profile. Second, it should be noted that judgements of valence are subjective. It may be that 'Gallery', for instance, was positive for some participants but negative for others. Despite this, participants without semantic control impairment performed at ceiling even in the *no association* condition (Experiment 1 = 95.7%, Experiment 2 controls = 97.8%), suggesting consensus on categorical valence. Furthermore, we used valence congruency as a binary predictor (positive/negative). One could instead observe parametric effects using participant ratings, with very positive words being more congruent with other very positive words than with mildly positive words. Doing so may provide a more sensitive measure. While a binary predictor was found to be sufficient in revealing behavioural effects, future researchers may wish to employ a continuous measure. Finally, it has been argued that valence is more important in the representation of abstract concepts which lack physical properties (Kousta et al., 2011). Evidence suggests interactions between valence and word concreteness in the recruitment of semantic control regions (Pauligk et al., 2019). In the current investigation, we did not manipulate concreteness; future research may benefit from considering this factor.

CONCLUSION

This study suggests that access to valence information during an explicit matching task is not automatic; task-irrelevant semantic information can impact retrieval. Such effects are particularly prominent in patients with impaired semantic control, likely due to difficulty in constraining internal information. Similarly, valence congruency facilitates judgements of global semantic relatedness, suggesting that valence constitutes an important feature of heteromodal concepts. These results provide novel insights into the relationship between semantic retrieval and valence processing.

AUTHOR CONTRIBUTIONS

Nicholas E. Souter: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; supervision; visualization; writing – original draft; writing – review and editing. **Ariyana Reddy:** Investigation; methodology; writing – review and editing. **Jake Walker:** Investigation; methodology; writing – review and editing. **Julián Marino Dávolos:** Conceptualization; writing – review and editing. **Elizabeth Jefferies:** Conceptualization; funding acquisition; methodology; supervision; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors have no competing interests to disclose.

OPEN RESEARCH BADGES

This article has earned Open Data and Open Materials badges. Data and materials are available at https://osf.io/fgjcs/.

DATA AVAILABILITY STATEMENT

All materials and data for the current study are publicly available on the Open Science Framework (https://osf.io/fgjcs/).

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