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TECHNICAL REPORT

Flexible use of perceptuomotor knowledge in lexical and semantic decision tasks

Ben D. Amsel

Department of Cognitive Science, University of California, San Diego

Address for correspondence:

Ben D. Amsel, Department of Cognitive Science, 0515

9500 Gilman Drive, La Jolla, CA, 92093-0515

Phone: (858) 534-6775 Fax: (858) 534-1128 Email:bamsel@ucsd.edu

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Wen-Hsuan Chan and Melissa Troyer, Editor
Center for Research in Language, 0526
9500 Gilman Drive, University of California, San Diego 92093-0526
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Della Rosa, P.
Psychology/Neuroscience, Universit á Vita Salute San Raffaele, Milan, Italy
IBFM, CNR, Segrate Milan, Italy
Dronkers, N.F.
University of California, Davis
Center for Research in Language, UC San Diego
Center for Aphasia and Related Disorders, VA Northern California Health Care System, Martinez, CA, USA
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Center for Research in Language, UC San Diego
Department of Cognitive Science, UC San Diego
Cappa, S.F.
Psychology/Neuroscience, Universit á Vita Salute San Raffaele, Milan, Italy
IBFM, CNR, Segrate Milan, Italy
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Flexible use of perceptuomotor knowledge in lexical and semantic decision tasks

Ben D. Amsel (bamsel@ucsd.edu)
Department of Cognitive Science, University of California, San Diego
9500 Gilman Drive, La Jolla, CA, USA, 92093-0515

Abstract

People know a lot about the perceivable properties of objects in their environments. We know, for example, that peacocks are colorful, ashtrays are smelly, and hammers are typically grasped in one hand. This study examines the extent to which several modality-specific object attribute ratings can account for performance in lexical and semantic decisions tasks. Seven continuously distributed variables from object attribute rating norms (smell intensity, color vividness, taste pleasantness, sound intensity, graspability, likelihood of motion, likelihood of pain) are used to predict decision latencies from three tasks varying in depth of semantic processing (living / nonliving; concrete / abstract; word / nonword). After controlling for standard word form and lexical variables, two modality-specific variables significantly predicted decision latencies in each task. Separate analyses were conducted for items denoting living things and items denoting nonliving things. In each task, modality-specific variables accounted for more variance in living thing latencies, and non-semantic variables accounted for more variance in nonliving thing latencies. These results suggest that modality-specific knowledge can be used flexibly to aid in lexical and semantic decision-making and are most consistent with "lexicon-free" models of word recognition.

Keywords: semantics; word recognition; decision-making; perceptual; motor; knowledge; mixed-effects models.

Introduction

Understanding written language requires a mapping between a visual form and previously acquired knowledge represented in long-term memory. Unlike memory retrieval in a digital computer, this process is sensitive to the task context in which language is comprehended. The present work addresses how our knowledge of objects can be used flexibly during language comprehension in varying task contexts. Specifically, I address the degree of flexibility in using perceptual and motor-related object knowledge during lexical and semantic decision-making tasks that vary in depth of semantic discrimination.

Varying the experimental task while holding the stimuli constant can exert a relatively persistent effect on the state of the cognitive and neural systems responsible for deriving meaning from language. Bermeitinger, Wentura, and Frings (2011) showed that semantic priming can be effectively switched on or off by manipulating task-related context. Participants exhibited priming for natural concepts, for which perceptual features are particularly salient, only when they had previously attended to perceptual properties of simple geometric shapes. In contrast, they only exhibited priming for artifactual concepts, for which function-related knowledge is particularly salient, when they had previously attended to action-related properties of the geometric shapes. Similarly, Tousignant and Pexman (2012) showed that the rated likelihood of interacting with an object predicted decision latencies on words denoting entities and actions only when participants were explicitly told to categorize the words based on the presence or absence of an entity, but not an action. In these and other studies that have manipulated the task-based context in which words are embedded (Grossman et al., 2002; Grossman et al., 2006; Hoenig, Sim, Bochev, Herrnberger, & Kiefer, 2008; West & Holcomb, 2000), systematic differences in behavioral performance or neural activity cannot be attributed to the eliciting stimulus, which is held constant, but rather reflect the current state of the system acting upon the stimulus.

Flexibility in word recognition

The notion of a graded and flexible word recognition process (rather than an all-or-none and encapsulated process) has long existed in the computational modeling literature. LaBerge and Samuels (1974) proposed a model whereby attention could be flexibly deployed to the phonological, orthographic, or semantic systems, and information could be passed between systems before it was fully processed. McClelland's (1979) cascade framework and subsequent connectionist implementations (e.g., Plaut, McClelland, Seidenberg, & Patterson, 1996) are inherently flexible in that sub-processing levels continuously provide a record of partial information to subsequent processing levels—and in the case of recurrent networks, partial information from previous time points is available within a single processing level. Depending on the nature of what this information is to be used for (e.g., understanding an utterance, making a lexical decision), the subset of activated information that is recruited to solve the task, and the time course of this recruitment, can naturally vary. For example, Elman's (1990) simple recurrent networks treat words not as discrete tokens corresponding to lexical entries, but rather as stimuli whose properties are interpretable from their dynamic effects on the internal state of the comprehension system. These effects are dynamic precisely because they "are always and unavoidably modulated by context" (Elman, 2004, p. 302).

Balota and Yap (2006) similarly claim that "there are no process-pure measures of word-recognition" (p. 5). To account for the role of context in word recognition, Balota and colleagues (Balota, Paul, & Spieler, 1999; Balota & Yap, 2006) have introduced the flexible lexical processor, wherein attentional control exerts a task-specific influence on word recognition by differentially recruiting particular pathways between components of the system. They contrast the naming task, which relies on connections between the orthography and phonology modules, and lexical decision, which relies more on connections between orthography and semantics, consistent with the known influence of conceptual knowledge on lexical decision performance. The word recognition literature includes much work on the influence of semantic variables in general, but relatively little work on the influences of specific kinds of semantic knowledge. The semantic memory literature, however, has made some progress in this area that is relevant for the current study.

Flexibility in conceptual processing

The notion of conceptual flexibility has recently been addressed by Hoenig et al. (2008) and by the Language and Situated Simulation (LASS) theory (Barsalou, Santos, Simmons, & Wilson, 2008; Simmons, Hamann, Harenski, Hu, & Barsalou, 2008), which is quite similar to Paivio's and Glaser's theories that posit verbal and pictorial codes (Glaser, 1992; Paivio, 1991). According to LASS, situated simulation (partial reactivation of the neural patterns formed during initial experiences with a word's referent) and activation of specific lexical forms occur in varying proportions, depending on the situation. Barsalou et al. (2008) assert that the situated simulation system and linguistic system produce overlapping distributions of activity in which activity in the linguistic system typically peaks before activity in the simulation system, but the level of activation is sensitive to task context. Situated simulation is thought to occur when correlated information in perceptual, motor, and introspective brain areas becomes active to represent a concept in a particular context. The current behavioral experiments provide an indirect test of this hypothesis in that several kinds of perceptual and motor-based knowledge about a common set of objects are used to account for performance in three different decision tasks.

Prior to the present study, only a handful of studies have examined the role of modality-specific semantic variables in visual word recognition (e.g., Amsel, Urbach, & Kutas, 2012; Grondin, Lupker, & McRae, 2009; Lynott & Connell, 2013). On the other hand, research conducted in the past ten years has led to a better understanding of semantic richness. One of the first results in this area that has stood the test of time is that concepts with more listed features (i.e., possessing greater semantic richness) facilitate performance in lexical and semantic decision tasks (Pexman, Lupker, & Hino, 2002; Pexman, Holyk, & Monfils, 2003). Most relevant for the current study, influences of semantic richness variables have recently been shown to vary flexibly across tasks (Hargreaves, White, Pexman, Pittman, & Goodyear, 2012; Pexman, Hargreaves, Siakaluk, Bodner, & Pope, 2008; Yap, Tan, Pexman, & Hargreaves, 2011). These authors argue that semantic richness is a multidimensional construct that can exert different magnitudes, and even directions of influence on behavioral performance, according to task demands. To the extent that object attribute ratings constitute modality-specific semantic richness, the present experiments also can inform the degree of flexibility in the role of semantic richness in lexical and semantic decision-making.

Present study

To what degree does access to modality-specific knowledge influence behavioral performance in semantic and lexical decision criteria? The main goal of the current study is to compare the effects of lexical and modality-specific conceptual variables on decision latencies in three different decision tasks. An additional goal of the current study is to understand the degree to which these influences vary by object domain (i.e., living thing and nonliving things). That is, to what extent do the effects of lexical factors and modality-specific conceptual factors differ across domains? Electrophysiological data suggest that the brain can begin to differentiate between words that refer to living versus nonliving things very rapidly following word form perception (Amsel, Urbach, & Kutas, 2013; Hauk, Coutout, Holden, & Chen, 2012). The word recognition system may be sensitive to this conceptual distinction early on in the processing stream, in which case one might expect a domain-level distinction in the kinds of conceptual variables that best predict decision latencies to items from either domain.

Modality-specific conceptual variables used in the current study are selected from a recent object attribute ratings study (Amsel et al., 2012), in which over 400 participants rated 559 object concepts on several perceptual and motor attributes: smell intensity, taste pleasantness, visual motion, color vividness, graspability (in one hand), likelihood of pain, and sound intensity. Of course, these attribute ratings are not the only recently obtained sources of conceptual content. Several studies have produced a number of novel conceptual variables (Bennett, Burnett, Siakaluk, & Pexman, 2011; Juhasz & Yap, 2013 Lynott & Connell, 2013; Lynott & Connell, 2009; McRae, Cree, Seidenberg, & McNorgan, 2005; van Dantzig, Cowell, Zeelenberg, & Pecher, 2011; Wurm, 2007). Some of these measures capture a weighted combination of information in multiple modalities. Imageability has been shown to reflect information about the visual modality more so than other modalities (Amsel et al., 2012; Connell & Lynott, 2012). Amsel et al. (2012) showed that Juhasz and Yap's (2013) sensory experience ratings are significantly correlated with color vividness, smell intensity, taste pleasantness, sound intensity, and visual motion ratings, and that Bennett et al.'s (2011) body-object interaction ratings are significantly correlated with pain likelihood, sound intensity, graspability, and visual motion ratings. In addition, Warriner, Kuperman, and Brysbaert (2013) showed that several of the Amsel et al. (2012) attribute ratings are significantly correlated with valence, arousal, and dominance. Given this clear role of several different unique influences of perceptuomotor knowledge, the present examination of several such variables will be useful in elucidating how various kinds of conceptual content are used to inform the decision-making system.

Finally, alongside several previous studies that assessed effects of naturally correlated item characteristics (Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004; Hauk, Davis, Ford, Pulvermüller, & Marslen-Wilson, 2006; Juhasz & Rayner, 2003; Yap & Balota, 2009), this work utilizes a design and statistical analyses that enable assessment of the unique effects of multiple correlated variables, rather than the dichotomization-plus-ANOVA approach, which has known limitations when applied to correlated quantitative variables (Cohen, 1983; MacCallum, Zhang, Preacher, & Rucker, 2002). In addition, data from the current behavioral experiments are analyzed using the linear mixed-effects model to avoid problems with applying the general linear model to data varying on two or more sampling units (i.e., subjects and words). The mixed-effects model can simultaneously account for variability due to random subject and item variance independently of the treatment effect, which has been shown to decrease Type I error and increase power, as compared to by-subject and by-item ANOVA, item-based regression, and random regression (Baayen, Davidson, & Bates, 2008; Quene & van den Bergh, 2008).

Experiments 1 & 2: Semantic decision tasks

Independent samples of participants performed two semantic decision tasks in which they decided whether a word denoted a living thing or nonliving thing (Exp. 1), or whether a word denoted a concrete or abstract entity (Exp. 2). More generally, a successful decision in a living/nonliving thing decision task presumably requires accessing some amount of knowledge about the characteristics of the object to which a noun refers, whereas a successful decision in a concrete/abstract decision task merely requires determining whether the noun refers to an object or not.

What types of knowledge are most predictive of the living versus nonliving things? Cree and McRae (2003) showed that visual color and motion features are particularly salient for living things. Therefore I expected that color vividness and visual motion would be the best predictors of Experiment 1 living thing decision latencies. The best predictors of nonliving thing decision latencies are less obvious to predict. Cree and McRae (2003) show that function features most clearly differentiate between nonliving things and other object categories; however, the sensory/motor knowledge reflected in modality-specific object attribute ratings is not sufficient to determine object function.

In theory, access to any kind of sensory/motor knowledge could be used to determine whether a word refers to a concrete or abstract entity. However, Connell and Lynott (2012) showed that concepts rated high on concreteness are not equally associated with all types of perceptual knowledge. They showed that concrete concepts (versus less concrete and abstract concepts) were specifically biased towards visual knowledge and to a lesser extent olfactory knowledge. Therefore, although performance in the concreteness decision task could be dependent on access to any kind of sensory/motor knowledge, visual and olfactory attributes are expected to be the strongest predictors of concreteness latencies.

Method

Participants

Thirty right-handed undergraduate students (17-25 years; 18 females) at the University of Toronto Scarborough (UTSC) completed the living/nonliving decision task for course credit, and 27 students (17-30 years; 15 females) from the same population completed the concreteness task. Participants had normal or corrected-to-normal vision and reported no neurological impairment. Participants had been speaking English as their primary language for at least ten years.

Materials

Experimental items were nouns denoting 207 concrete concepts (101 nonliving things, 77 creatures, 29 fruits and vegetables) selected from the MRC Psycholinguistic database (Coltheart, 1981) and ranging in concreteness from 543 to 662 (M = 606, SD = 22). Items were measured on number of letters, number of syllables, number of phonemes, word frequency (natural log of HAL frequency; Lund & Burgess, 1996) and number of orthographic and phonological neighbors (Balota et al., 2007). In order to minimize collinearity, the first principal component of number of letters, syllables, and phonemes (proportion of original variance: 89%), and the first principal component of number of orthographic and phonological neighbors (proportion of original variance: 95%) replaced the original variables in the upcoming analyses. Familiarity ratings (degree of familiarity with the entity to which the word refers) were taken from McRae et al. (2005). The modality-specific variables consisted of smell intensity, taste pleasantness, visual motion, color vividness, graspability (in one hand), pain likelihood, and sound intensity ratings (Amsel et al., 2012). Abstract words (N = 207) were selected for use in the concreteness task from the MRC Psycholinguistic database and ranged in concreteness from 183 to 399 (M = 332, SD = 42). Abstract words were matched to the concrete words on word frequency, letter length, and familiarity. Table 1 contains the Pearson's correlation coefficients between all predictors.

Table 1: Correlations among item characteristics; * $p < .05$ (95% confidence interval around the estimate does not contain zero; determined with 100,000 replications of the accelerated bias-corrected bootstrap); CS: principal component scores.

Variable	Freq.	Neigh.	Fam.	Pain	Smell	Color	Taste	Sound	Grasp	Motion
Length CS	-0.48*	-0.72*	-0.1	-0.06	-0.03	0.19*	0.1	0	0.11	-0.08
Freq.	--	0.46*	0.46*	0.06	-0.09	-0.04	-0.16*	0.15*	-0.09	-0.06
Neighborhood CS		--	0.13	0.04	0.04	-0.14*	-0.06	0.03	-0.07	0.03
Fam.			--	-0.34*	-0.15*	0.13*	0.07	-0.37*	0.37*	-0.48*
Pain				--	-0.07	-0.26*	-0.39*	0.53*	-0.32*	0.35*
Smell					--	0.23*	0.58*	0.04	-0.18*	0.13
Color						--	0.41*	-0.15*	0.15*	-0.1
Taste							--	-0.36*	0.28*	-0.24*
Sound								--	-0.55*	0.47*
Grasp									--	-0.52*

Procedure

Participants performed a living/nonliving thing or concrete/abstract decision task individually in a dimly lit room. The experiments were implemented with E-Prime (Psychology Software Tools, Inc). For the living/nonliving task, participants were instructed, upon viewing each word, to judge as quickly and accurately as possible whether the word denoted a living or nonliving thing. They were informed that fruit or vegetable concepts could be included, and should be categorized as living. Participants in the concreteness task were instructed to decide as quickly and accurately as possible whether each word denoted an abstract or concrete word. They were informed that concrete words denote "perceivable entities that you could see, hear, touch, smell, or taste."

The experimenter monitored 12 practice trials (containing either (a) six living things including one fruit concept and one vegetable concept and six nonliving things or (b) six concrete items selected from the previous 12 and six abstract items) to ensure participants understood the task and re-administered them if there was doubt about participants' understanding. All items were presented in one block, in a different random order for each participant. Each trial began with a fixation ("+") presented for a random duration between 1200-1800 ms, followed by the target word which remained onscreen until a response was recorded, followed by a 1000 ms white screen. Participants sat at a viewing distance of 70 cm from a 17" monitor with 800x600 resolution and text was presented in size 18 black Tahoma Bold font against a white background in the middle of the screen. Participants signaled their response with a PST Serial Response Box (Psychology Software Tools, Inc.). In the living/nonliving task, half of the participants signaled living thing items with their dominant hand, and the other half signaled non-living thing items with their dominant hand. In the concreteness task, responses were not counterbalanced; all participants signaled concrete words with their dominant hand because I was not interested in responses to the abstract items.

Data analysis

Trials with decision latencies less than 200 ms or greater than 2000 ms were removed from further analyses, which affected less than 2% of all trials. The reciprocals of the remaining latencies were taken to reduce positive skew, and multiplied by -1 to retain the original sign (additional model fits using the logarithmic transformation did not yield qualitatively different model results). This transformation was undertaken to bring outlying response times closer to the majority of responses, which decreases the possibility that estimated model parameters are disproportionally influenced by a handful of outlying trials. All variables were then transformed to z-scores to facilitate comparisons across scales. Collinearity was assessed by inspecting variance inflation factors (VIF) of each term in each model. VIF is a measure of the amount that the variance of a parameter estimate is increased due to collinearity. No VIF were larger than three, which is well below a suggested upper limit of 10 (Cohen, Cohen, West, & Aiken, 2003).

The linear mixed-effects model was used for all data analysis. Models were fitted in the R environment (R Development Core Team, 2012) with the lmer function (Bates, Maechler, & Bolker, 2011). Statistically significant random variability existed among the by-subject intercepts and by-item intercepts in all models presented herein (as determined by likelihood ratio tests). The random effects structure of all models therefore included two parameters specifying the variance of the by-subject and by-item adjustments to the intercepts, as well as a third parameter specifying the correlation between these two random effects.

Mixed-effects models were fitted to each set of decision latencies in two steps much like hierarchical linear regression analysis. The first model contained word frequency, familiarity, the component scores from the length PCA analysis, and the component scores from the neighborhood PCA analysis. First-order autocorrelation among response times was accounted for by including the directly preceding response time in each trial (i.e., RT_{t-1}) in each model. In naming tasks, slow and fast responses are often followed by slow and fast responses, respectively (Taylor & Lupker, 2001). These carryover effects may reflect a slowing of time perception after more difficult trials (Taylor & Lupker, 2006; Taylor & Lupker, 2007), which importantly could occur in any task involving judgments on multiple stimuli. Inclusion of this measure can substantially decrease the degree of residual variance in a model, and thus decreases the standard errors of variables of interest.

The second model assessed the unique effects of the modality-specific semantic variables while controlling for the above variables. Separate models were fitted to decision latencies in each task. Within each task, three models were fitted corresponding to all responses, responses for living thing items, and nonliving thing decision latencies to assess the extent to which the effects of these variables differ as a function of object domain. In addition, a recent theoretical analysis and accompanying simulation studies (Barr, Levy, Scheepers, & Tily, 2013) demonstrated that by-subject random slopes for predictor variables of interest should be included in linear mixed-effects models whenever possible. Given the relatively large number of predictors in the current step 2 models, fitting a maximal random effects structure was not possible in most cases due to failure of the estimation algorithm to converge. However, given the importance of including by-subject random slopes for variables of theoretical interest (in contrast to control variables), these random effects terms were included for certain semantic variables in each model as follows. I fitted an initial model containing all the control variables and the semantic variables, including random effects of by-subject and by-item intercepts. In a subsequent model I added random effects of by-subject slopes for any semantic variable that had a probability value of less than 0.05 in the initial model based on 100,000 iterations of Markov chain Monte Carlo sampling (Baayen et al., 2008). The bottom half of Table 2 presents the standardized coefficients for each semantic variable in the subsequent model, where statistical significance (*$p < .05$; **$p < .01$; ***$p < .001$) is based on the standard normal distribution (computing probability values using Markov chain Monte Carlo sampling for mixed-effects models with by-subject random slopes is not trivial and is not attempted here).

Table 2: Standardized coefficients from two-step hierarchical mixed-effects regression analyses of decision latencies from two semantic decision tasks and a lexical decision task. Initial models containing form and lexical variables were fitted on decision latencies for all items, living thing items, and nonliving thing items. Second-step models were forced to include these same variables and seven modality-specific semantic variables, in addition to by-subject random slopes for certain semantic variables (see text for details). Initial variance signifies the percentage of variance due to item variability that was accounted for by the form and lexical variables in the initial models (see text for calculations). Residual variance signifies the percentage of variance due to items accounted for by the semantic variables over and above the initial variables in the second models. Total variance is the sum of each, and constitutes the total percentage of explained variance. CS: principal component scores. * $p < .01$; ** $p < .001$.

Variable	Living / Nonliving			Concrete / Abstract			Word / Nonword		
Form & Lexical	Total	LT	NLT	Total	LT	NLT	Total	LT	NLT
RT -1	.165**	.181**	.158**	.050**	.106**	.144**	.185**	.208**	.169**
Length (CS)	-.003	-.051	.029	-.021	-.066	.020	.027	-.009	.057
Neighborhood (CS)	.008	-.036	.068*	.017	.002	.041	.018	-.015	.061
Word frequency	-.118**	-.184**	-.118**	-.126**	-.171**	-.146**	-.204**	-.244**	-.214**
Familiarity	.019	.077	-.065*	-.063*	-.058	-.096*	-.090**	-.084	-.127**
Initial variance	*13%*	*21%*	*51%*	*22%*	*30%*	*40%*	*53%*	*46%*	*75%*
Semantic									
Pain likelihood	-.033	-.078	.017	-.052	-.075	-.035	-.054	-.089	.002
Smell intensity	-.031	.013	-.058	-.071	-.030	-.048	-.047	.010	-.095
Color vividness	-.042†	-.057	-.006	-.031	-.005	-.041	-.038	-.059†	.063
Taste pleasantness	-.008	.013	.198	-.030	.036	-.031	-.034	.032	-.003
Sound intensity	.012	-.001	-.043	.006	.004	-.050	-.019	-.061	-.048
Graspability	.049	.085	-.027	-.012	.083	-.067	.033	.066	-.028
Visual motion	-.090**	-.101	.048	-.043	.059	.023	.003	-.009	.039
Residual variance	*18%*	*26%*	*3%*	*11%*	*6%*	*1%*	*6%*	*9%*	*3%*
Total variance	*31%*	*47%*	*54%*	*33%*	*36%*	*41%*	*59%*	*55%*	*78%*

Results

Accuracy

Mean accuracy in the living/nonliving task was 96% and ranged from 83% to 100% (one participant). Mean accuracy in the concreteness task was 94% and ranged from 77% to 100% (one participant).

Living/nonliving decision latencies

Three items were excluded from analyses: “pepper” and “stork,” for low accuracy (< 50%), and “nightingale” for disproportionate model influence (i.e., the inclusion of this outlier would have a disproportionately large influence on model estimates). Overall average latency was 686 ms (living things: 678 ms; nonliving things: 693 ms).

Table 2 contains the standardized coefficients in all statistical models. In addition, the variance components in mixed-effects models can reveal the degree to which the item-based variability is due specifically to item characteristics (Locker, Hoffman, & Bovaird, 2007). For example, in the initial model of living thing RTs, the variance of the by-item random effect in the fitted model ($s^2 = .069$) is divided by the variance of the by-item random effect in an “empty” model including the same random effects structure but excluding the item characteristics ($s^2 = .087$). Therefore the proportion of by-item variability accounted for by the item characteristics in the initial model is 21% (1 – (.069 / .087)). In the second (semantic variables included) model of living thing RTs, the variance of the by-item random effect in the fitted model is divided by the variance of the by-item random effect in the initial fitted model, from which one can compute the percentage of residual item-based variance explained by the modality-specific predictors. These percentages are shown for every model in Table 2. This may be a more useful measure than the typically reported R^2, because the denominator of R^2 (i.e., total variability) encompasses variability due to subjects and to error, which are independent of the item characteristics.

Concreteness decision latencies

Two items, “fawn,” and “nightingale,” were removed from analyses due to low accuracy (< 50%) and disproportionate model influence, respectively. Overall average latency was 789 ms (abstract items: 856 ms; concrete items: 753 ms). Within concrete items, average latencies for living and nonliving thing items were 738 ms and 767 ms respectively. See Table 2 for statistical results.

Discussion

Among the lexical and form variables, word frequency generally was the strongest predictor of decision latencies for all sets of items in both tasks, followed by familiarity and neighborhood.

Living / nonliving decision latencies

Among the semantic variables, higher visual motion and graspability were associated with faster decisions among all items. Higher visual motion and, to a lesser extent, higher pain likelihood and color vividness were associated with faster decisions among living thing items. No semantic variables significantly predicted nonliving thing decision latencies. The significant effect of visual motion was not surprising given its ability to differentiate between living and nonliving things (Cree & McRae, 2003). The unpredicted marginal influence of pain likelihood among living thing items is interesting in that animals with high pain likelihood ratings (e.g., alligator, python) were not necessarily typical “living things.” Nineteen of the 20 fastest latencies across decision categories were members of the “creatures” category. In addition, decision latencies were fastest for the creature category and slowest for the nonliving thing category, which suggests that the living/nonliving decision criterion caused a domain-level typicality effect (i.e., participants may have treated “animals” as prototypical “living things”).

To assess the possibility of a typicality effect within the creature category, I obtained typicality ratings for these concepts available from O’Connor, Cree, and McRae (2009), in which participants rated how typical each word was of the corresponding category (“animal”). No association was present between typicality and decision latency among items that belong to the “animal” category ($R^2 = .03$), consistent with the presence of a between-category typicality effect but the absence of a within-category typicality effect. Although not shown in Table 1, I also fitted separate models to the decision latencies for creatures and fruits and vegetables. Significant conceptual variables for creatures were likelihood of pain and taste pleasantness, and the only significant variable for fruits and vegetables was color intensity. Therefore, the inclusion of fruits and vegetables in the living/nonliving decision task may have posed a particular difficulty, despite the instructions to categorize all living things together.

In contrast to the finding of multiple semantic predictors of living thing decision latencies, none of the semantic variables significantly predicted nonliving thing decision latencies. The total item-based variance in the living and nonliving latencies that was accounted for by all predictors was 47% and 54% respectively. However, the semantic variables only accounted for 3% of additional variance in the nonliving decision latencies, as compared to 26% of additional variance in the living thing decision latencies. The lack of influence of semantic variables in accounting for nonliving thing latencies is somewhat puzzling given that nonliving things can vary to some extent on all of these modality-specific attributes. It is possible that participants primarily used function-based knowledge for positive evidence of membership in the nonliving thing category. The most salient difference between nonliving thing concepts and living thing concepts in the McRae et al. (2005) norms is the greater number of function features (e.g., "used for cooking") listed for nonliving things (Cree & McRae, 2003). However, functional knowledge by definition involves more than the sensory properties or motor affordances associated with a given object category. In part for this reason, the Amsel et al. (2012) attribute norms do not contain ratings of function, and although graspability ratings may be correlated with function for certain object categories (i.e., tools), the relationship is likely less prominent or nonexistent for many other object categories.

Concreteness decision latencies

Faster decisions were significantly associated with higher smell intensity and likelihood of pain ratings. The olfactory effect is an independent replication of Amsel et al. (2012) and suggests that smell-related knowledge may be a central cue to concreteness—specifically in online concreteness judgments. In fact, Amsel et al. (2012) collected response times for ratings of seven sensory/motor attributes and showed that olfactory and gustatory attributes were rated more quickly than the other five attributes. Perhaps the profile of perceptual knowledge types that most effectively cues concreteness varies not only by the level of concreteness (Connell & Lynott, 2012) but also according to the temporal task constraints (i.e., how quickly knowledge is accessed in the service of successful task performance).

Finally, the slower average latencies for the concreteness task versus the living/nonliving thing task appear to contradict an earlier suggestion about task differences. It was suggested that performing the living/nonliving thing decision task requires accessing specific information about the object to which a noun refers whereas the concreteness task merely requires accessing the knowledge that the noun refers to an object—any object will do. Why then did participants respond more quickly in the former task? One possibility is the difference in scope between the set of all concrete entities versus all concrete or abstract concepts (i.e., all concepts). Perhaps the living/nonliving task enables participants to maintain a more constrained attentional set of possible upcoming stimuli, which translates into faster semantic access and/or decision processes. Reviewers suggested the additional possibilities that the conceptual representations of living things might be particularly rich in comparison to the less rich and possibly more difficult to access representations of nonliving things, and that people may be more familiar with discriminating between living and nonliving things versus concrete and abstract decisions.

Experiment 3: Lexical decision task

In contrast with the semantic decision tasks, which unarguably require recruitment of semantic information, lexical decisions do not logically require access to semantic information. Positive evidence that a letter string is a valid English word could solely consist of amount of prior perceptual experience with a particular letter string. That said, the influence of semantic knowledge on lexical decisions is clear (Becker, Moscovitch, Behrmann, & Joordens, 1997; Joordens & Becker, 1997), including effects of semantic richness (e.g., Grondin et al., 2009; Pexman et al., 2002, 2008).

Facilitation in the lexical decision task has been reported for a number of sensory or motor-related semantic measures. Faster response times have been linked to words associated with higher scores on number of listed visual form, tactile, and taste features (Grondin et al., 2009), perceptual strength ratings (Connell & Lynott, 2012), body-object interaction ratings (Siakaluk, Pexman, Aguilera, Owen, & Sears, 2008), and sensory experience ratings (Juhasz, Yap, Dicke, Taylor, & Gullick, 2011). Words denoting entities rated high on usefulness or danger are recognized faster and more accurately after controlling for several variables (see overview in Wurm, 2007), and Amsel et al. (2012) showed that their pain likelihood and smell intensity measures may be highly correlated with Wurm's (2007) danger and usefulness ratings, respectively. Finally, Amsel et al.'s (2012) re-analysis of the Grondin et al. (2009) lexical decision latencies revealed significant effects of visual motion and taste pleasantness ratings.

This growing body of studies suggests that our knowledge about the sensory/motor properties of objects and our perceptual and physical experiences with those objects both appear to influence how quickly we can recognize words referring to those objects. Experiment 3 adds to this endeavor by assessing the influences of several modality-specific variables on lexical decision latencies for words referring to living and nonliving thing concepts.

Methods

Participants

Thirty undergraduate students (17-24 years; 16 females) at UTSC participated for course credit. Participants had normal or corrected-to-normal vision and reported no neurological impairment. Inclusion criteria included right-handedness, and > 10 years speaking English as a first language.

Materials

The 207 experimental items were identical to Experiments 1-2. The 207 nonwords were generated from the English Lexicon Project by changing one or two letters in a target word, where the location of the letter change alternated across different words including early, middle, and late positions. The pronounceable nonwords (e.g., "yait," "tane") occupy a middle ground in the range from most word-like (pseudohomophones: "dait") to least word-like (non-pronounceable: "dtia") nonwords.

Procedure

The procedure was identical to Experiments 1-2 with the exception of the decision criterion: participants were instructed to decide as quickly and accurately as possible whether each letter string denoted a valid English word. Given that decision latencies for valid letter strings were of interest, all participants responded to these stimuli with their right hands.

Statistical analysis

Statistical analysis was identical to the analysis used in Experiments 1-2.

Results

Accuracy

One subject's data were removed from further analyses due to low accuracy (59%). For the remaining participants, mean accuracy was 93% and ranged from 90% to 99%.

Decision latency

Overall average latency for the 207 experimental items was 604 ms. Average latencies for living and nonliving thing items are 602 and 607 ms, respectively. Table 2 presents statistical results including model estimates for all items and living and nonliving thing items separately.

Discussion

Consistent with past literature (e.g., Balota et al., 2004; Yap & Balota, 2009), word frequency exerted a particularly strong influence on lexical decision latency for both living and nonliving thing items. Not surprisingly, rated familiarity for living thing concepts and especially nonliving thing concepts were also strong predictors. More interesting are the significant influences of modality-specific attributes. Higher ratings of pain likelihood and smell intensity were associated with faster lexical decisions among all items. The effect of pain likelihood appears to be domain-specific. It is entirely driven by the living thing items, despite the fact that the ten words with the highest likelihood of pain ratings are all nonliving things (e.g., "whip," "cannon," "bomb"). Similarly, the overall significant effect of smell intensity appears to be exclusively driven by the nonliving thing items. Examples of nonliving things rated highest on smell intensity are "toaster," "oven," and "tractor," which is interesting because these objects do not emit odors directly but rather are experienced in close proximity to odor-producing organic matter. This particular finding suggests that people may be activating real-world situational knowledge that in turn could constitute positive evidence for a word judgment in the lexical decision task. A domain-level difference also appears in the residual variance explained by the control variables and semantic variables. Among nonliving thing items, the semantic variables only explained 4% of the item-based variance whereas these same variables accounted for 16% of the item-based variance among the living thing concepts.

The influence of these modality-specific conceptual variables on lexical decision latencies strengthens the assertion that knowledge related to perceptual experience is not only accessed during word processing but can be used to shape decisions that can be made without this level of conceptual specificity. These results also suggest that word recognition researchers may want to take into account domain-level information when designing and analyzing future studies. Finally, the finding that variables related to perceptuomotor knowledge about a word's referent can influence lexical decision times is not consistent with mental lexicon models of lexical decision task performance. According to these models (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Levelt, 1989), this task requires checking whether the orthographic input matches an existing entry in a mental lexicon. It is unclear why this process should be expedited when the input refers to a particularly colorful or smelly object. The present results are most consistent with "lexicon-free" models in which semantic access is an obligatory process initiated upon presentation of any orthographic form (e.g., Dilkina, McClelland, & Plaut, 2010; Elman, 2004; Laszlo & Federmeier, 2011; Plaut et al., 1996).

General Discussion

The present study assessed the effects of seven different measures of modality-specific knowledge on behavioral decision latencies from three tasks varying in the depth of semantic discrimination (living/nonliving; concrete/abstract; word/nonword). After controlling for the non-semantic variables, modality-specific semantic variables influenced decision latencies in each task. These data suggest that when we encounter an object name in the context of a decision task, our response to that word can be shaped by our knowledge about how the object looks, feels, and smells as well as by our knowledge of the likelihood that it would be in motion and even cause pain.

It is important to acknowledge the exploratory nature of these analyses. Several different kinds of modality-specific predictors were examined, and in some cases specific theory-driven predictions about how a particular type of knowledge should influence performance in a specific task were unavailable. At first glance, the divergence in the effects of these modality-specific variables across tasks, and among recent studies, appears to be a concern. In comparison with word frequency, for example, the influences of specific kinds of knowledge are much smaller in magnitude and are less likely to produce robust effects across different tasks and experiments. However, our understanding of how knowledge is organized and accessed in semantic memory across different contexts will be increased by determining (1) which among recently created measures of conceptual knowledge are recruited during semantic and lexical decision tasks and (2) the magnitudes of their influences.

The results of the concreteness and lexical decision experiments (along with Amsel et al., 2012, and Grondin et al., 2009) converge to cement the importance of knowledge types beyond vision—particularly gustatory and olfactory information. Smell intensity and number of taste features were significant predictors of lexical and concreteness decision latencies in the current experiment and Grondin et al. (2009), respectively. Why should concreteness and especially lexical decisions be facilitated for words that refer to particularly smelly or tasty objects? For one, "if people have eaten something, then they know it is concrete, and they know that its name is a word" (Grondin et al., 2009, p 13). Functional neuroimaging studies show that silently reading words that refer to objects with particularly salient tastes and smells leads to increased activation in olfactory (Gonzalez et al., 2006) and gustatory (Barros-Loscertales et al., 2012) cortices in contrast to other kinds of words. If access to gustatory or olfactory knowledge is a routine part of the reading process for object nouns, then this information would constitute additional evidence that these letter strings are in fact valid English words. However, a reviewer points out that people could eat things for which they couldn't name, or for which there is no name. They suggest the opposite logic: If you read a word that is associated with an experience of taste or smell, then you can be more confident that it's a word.

Taken as a whole, the current results also highlight the potential importance of considering object domain in lexical and semantic decision task performance. The best predictors of decision latencies among all words were not the same as the best predictors of living thing and nonliving thing decision latencies in any task. In addition, the percentage of item-based variance explained by the semantic predictors was always higher for the living thing items whereas the form and lexical predictors always accounted for more variance in the nonliving thing items. That is, access to knowledge about the perceptible properties of objects is more important for processing living thing concepts when the task requirement is related to this distinction, but it remains useful even when task requirements are unrelated to perceptual properties. Finally, it was somewhat remarkable to find that the semantic variables explained more variance in living and nonliving thing decision latencies in the lexical decision task versus the concreteness decision task. Taken together with the recent reports of perceptually-related semantic effects on lexical decision performance, this result suggests that making a lexical decision may involve access to a more varied array of perceptual and motor object knowledge than was previously appreciated (at least by some researchers)—despite the fact that a positive response in this task could theoretically be based purely on stimulus familiarity.

The present results are most consistent with a word recognition system wherein conceptual information acquired from multiple sensory modalities can be accessed quickly enough to inform a decision system. The different patterns of influence across the three tasks are also consistent with at least some degree of flexibility in the recognition system. Discussions of flexibility in lexical and semantic processing can be found in the computational modeling, word recognition, neuroimaging, and semantic memory literatures (see Introduction). One key assumption underlying many of these views is that word meanings are not static, but instead consist of a temporarily activated subset of available knowledge in long-term memory that is unavoidably influenced by context (e.g., Elman, 2004). According to the flexible lexical processor account (Balota et al., 1999; Balota & Yap, 2006), task-related context influences task performance through an attentional control mechanism that increases the priority of computations in a particular information module (e.g., phonology, meaning). This notion of attentional control is consistent with the current finding that the depth of semantic discrimination required to perform each decision task was at least monotonically associated with the proportion of item-based variance accounted for by the semantic variables. That said, this relationship broke down if separate models were fitted to living versus nonliving thing items, which suggests that increasing the depth of semantic discrimination required for task performance does not necessarily have a transparent relationship to the kind or degree of activated semantic knowledge.

The current results along with previous studies (Bermeitinger et al., 2011; Grondin et al., 2009) can also be used to argue for an additional fractionation of the "meaning" or "semantics" modules in various word recognition models (Balota et al., 1999; Plaut et al., 1996), whereby a particular kind of conceptual information (e.g., visual, motor, taste knowledge) can be activated in some contexts and not others. An important challenge for future research is to determine the level of specificity that attentional control (or any neural mechanism of endogenous control) can exert on access to finer-grained conceptual content such as visual versus motor knowledge, or even different kinds of visual knowledge.

The flexible lexical processor and many connectionist models of word recognition (Seidenberg, 2005) posit separate components of orthography, phonology, and meaning. As a more general theory of lexical processing, Barsalou and colleagues' LASS account assumes that processing pictures, words, scents, or any other meaningful stimulus involves a mixture of simulation and language systems, where simulation is defined as partial re-activations of patterns of activity originally involved in sensory/motor processes that enable deep conceptual processing (e.g., relations between features, concepts, and categories). Barsalou et al. (2008) assume that simulations can become activated somewhat rapidly and automatically, but that statistical regularities entrenched in a mature language system can influence task performance even more rapidly following word onset. Simmons et al. (2008) provided fMRI evidence for a neurocognitive distinction between these two systems. They determined which brain regions were specifically more activated when people performed a word association task (versus a situation generation task), and vice versa. They then asked participants to list properties of objects for several seconds. In support of the LASS theory, they showed that the anatomical distribution of BOLD activity during early property listing (less than 7 sec.) and late property listing (greater than 7 sec.) was more similar to the activations during the word association task and situation generation task, respectively. In addition, recent experiments by Louwerse and colleagues have supported the main assumptions of LASS theory (M. Louwerse & Connell, 2011; M. M. Louwerse, 2008; M. M. Louwerse & Jeuniaux, 2010). LASS theory makes two claims that are supported by the present data. Most generally, Barsalou et al. (2008) argue for context-dependent flexible recruitment of conceptual and linguistic information: “We assume that different mixtures of the two systems underlie a wide variety of tasks. […] Depending on task conditions, conceptual processing may mostly consist of linguistic processing or simulation. Under many conditions, both may contribute equally. We assume that both processes are typically engaged to some extent” (p. 251).

The current results are consistent with the LASS assumption of different mixtures of the simulation and language systems, and suggest that the influence of (1) activated conceptual information in multiple modalities, and (2) form-based and lexical information vary flexibly on the basis of the decision criteria and its interaction with object domain. Performance in the living/nonliving thing decision task is based on specific knowledge about the nature of concrete objects, and was influenced more by semantic variables than form-based and lexical variables according to item-based variance proportions. Conversely, in the lexical decision task form and lexical variables explained almost ten times more item-related variance in decision latencies than did semantic variables.

Taken together, the current results along with comparable recent work suggest that a surprisingly diverse variety of modality-specific conceptual knowledge types are accessed in a flexible manner during semantic and lexical decision tasks. The lexical decision results in particular are most consistent with “lexicon-free” models in which semantic access is obligatory (e.g., Dilkina et al., 2010; Elman, 2004; Laszlo & Federmeier, 2011; Plaut et al., 1996) and less consistent with models that posit a separate mental lexicon (e.g., Coltheart et al., 2001; Levelt, 1989). In sum, alongside other recent work in this area (Amsel et al., 2012; Connell & Lynott, 2012; Juhasz et al., 2011; Lynott & Connell, 2013; Pexman et al., 2008; Siakaluk et al., 2008a, 2008b; Wurm, 2007; Yap et al., 2011), the current results bring us a little closer to understanding how our experiences with objects in our environment can influence reading and decision-making.

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