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Verb Generation Priming Involves Conceptual Implicit Memory

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Brain activation patterns differ and generation latencies are reduced when generating verbs to repeated nouns (Raichle et al., 1994). Amnesic participants show normal magnitude of priming (Seger et al., 1997). Despite its importance in neuropsychology, verb generation priming is not well characterized psychologically. Six behavioral studies found that verb generation priming was specific to the verb rather than to the noun or the noun–verb pair, was equivalent after overt or covert generation and after reading verbs or generating verbs, was affected by levels of processing, and transferred completely across languages in bilinguals. These results indicate that verb generation priming involves priming of particular responses and happens at a conceptual level. These findings provide new insights about the significance of brain imaging and neuropsychological studies involving verb generation priming.

Verb generation may be the most widely used experimental task in functional neuroimaging studies investigating the brain bases of semantic thought (McCarthy et al., 1993; Petersen et al., 1988, 1989; Raichle et al., 1994; Warburton et al., 1996; Wise et al., 1991). Participants are presented with nouns (e.g., airplane) and are asked to generate for each one a related verb (e.g., fly). In neuroimaging studies, brain activation during verb generation is compared to that occurring when participants read the presented nouns aloud. The generation and reading tasks are thought to have similar perceptual (visual analysis of words) and motor (producing an answer aloud) de-

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mands, but to differ in the degree of semantic analysis required to generate a verb versus read a noun. The difference in semantic analysis produces greater activation in left inferior prefrontal cortex, anterior cingulate gyrus, and right inferior lateral cerebellum (Petersen et al., 1988, 1989; Raichle et al., 1994). The left frontal activation is seen across a wide variety of semantic tasks, including abstract/concrete word judgment (Demb et al., 1995; Gabrieli et al., 1996), living/nonliving word and picture judgments (Kapur et al., 1994; Wagner et al., 1997), category membership judgment (Petersen et al., 1988, 1989), word association generation (Blaxton et al., 1996), sentence completion (Nathaniel-James et al., 1997), and synonym generation (Klein et al., 1995). Further, the left frontal activation associated with verb generation is found in studies using both position emission tomography (PET; Petersen et al., 1988, 1989; Raichle et al., 1994) and functional magnetic resonance imaging (fMRI; Seger et al., 1997a; Thompson-Schill et al., 1997). Thus, verb generation involves a process mediated by left prefrontal cortex that is widely used in semantic thought.

In the basic verb generation task, the nouns are never repeated. However, when nouns are repeated across blocks, performance changes as do the brain systems that support performance. Verbs are generated more quickly, and the left prefrontal, cingulate, and cerebellar activations are reduced, as seen in both PET (Raichle et al., 1994) and fMRI (Seger et al., 1997a) studies. Conversely, Raichle et al. (1994) found a relative increase in activation in bilateral sylvian-insular cortex. Reintroduction of novel nouns reverses these changes: Participants respond more slowly, and the pattern of brain activity returns to what it was when participants were first generating verbs to novel nouns. In the verb generation task, therefore, changes in behavior are linked to dynamic changes in brain systems. Furthermore, the changes in behavior and brain systems are specific to repetition of particular stimuli and/or responses, rather than due to general familiarity with the task.

Seger et al. (1997b) examined performance of amnesic patients on a repeated verb generation task modeled after the Raichle et al. (1994) PET study. The goal was to investigate whether verb generation facilitation was dependent on declarative memory (which is impaired in amnesics) or nondeclarative memory (which is typically preserved in amnesics). Participants performed five blocks of verb generation: four blocks of repeated nouns followed by a block of novel nouns. Amnesic patients showed the same pattern of results as normal control participants: Generation time decreased across blocks of repeated nouns and returned to its initial level on the final novel noun block. Thus, verb generation priming is independent of the hippocampal and diencephalic brain systems that are damaged in global amnesia. Furthermore, verb generation is best characterized as a nondeclarative memory task.

The aim of the present study was to further explore the psychological nature of the changes in behavior and brain systems that occur with repeated verb generation in normal participants. The first experiment investigated whether facilitation of verb generation to repeated nouns still occurred when methodological changes were made in the procedure used by Raichle et al. (1994). Raichle et al. (1994) termed the changes seen in repeated verb generation as ''habit development'' or ''skill learning.'' They further hypothesized that the task involved automatization of particular stimulus–response pairs. Experiment 2 tested whether priming was due to stimulus (noun) repetition, response (verb) repetition, or (as assumed by Raichle et al.) paired stimulus–response (noun–verb) learning.

We hypothesized that facilitation in verb generation is a form of conceptual repetition priming. Conceptual forms of repetition priming are expressed on tests in which participants are given cue stimuli that are semantically related to previously studied target items. Conceptual priming differs from perceptual repetition priming, in which participants are given cue stimuli that are perceptually degraded versions of the target stimuli. Conceptual priming tasks include word associate priming and category exemplar priming (Roediger & McDermott, 1993). In terms of behavior, in both verb generation and conceptual priming the target word is more likely to be produced and/or is produced more quickly in response to a previously presented conceptually related stimulus than a novel stimulus. In terms of brain systems, both repeated verb generation and conceptual priming yield reductions of left frontal brain activation (Blaxton et al., 1996; Gabrieli et al., 1996; Raichle et al., 1994). The finding of Seger et al. (1997b) that amnesic patients are preserved on verb generation priming is consistent with this characterization, as amnesics show preserved performance on many (but not all) conceptual priming tasks. It should be noted that conceptual priming is not a unified phenomenon: conceptual priming tasks can be dissociated from each other through study phase manipulations of conceptual processing (Schacter & McGlynn, 1989; Vaidya et al., 1997).

Experiments 3 through 6 explored the commonalties between verb generation priming and other conceptual priming tasks. Experiment 3 investigated whether verb generation priming had motor or perceptual components by comparing overt production of a verb (speaking) with covert production. Experiments 4 and 5 investigated whether greater study-phase conceptual processing of verbs (generating versus reading a verb aloud or performing a semantic versus orthographic judgment about a verb) increased verb generation priming, as it does in some (Blaxton, 1992; Hamann, 1990; Rappold & Hashtroudi, 1991; Srinivas & Roediger, 1990), but not all (Schacter & McGlynn, 1989; Vaidya et al., 1997), conceptual priming tasks. Experiment 6 examined verb generation priming across languages; any transfer across languages would imply conceptual priming, as the perceptual (orthographic and phonological) features of words and lexical representations of words differ across languages. We compared bilinguals, who performed verb generation in Spanish and then in English, with monolinguals who performed in English throughout.

EXPERIMENT 1

Experiment 1 examined whether facilitation within the verb generation task found by Raichle et al. (1994) was still present when the method of stimulus presentation was altered to allow participants unlimited time to make responses. A fixed presentation rate of 1.5 s per noun, without regard to whether participants made a response or when a response was made, was used by Raichle et al. because PET imaging requires that stimuli be presented at a constant rate and duration. In our pilot work, however, participants often lagged behind and generated verbs corresponding to previous nouns. Therefore, in Experiment 1 participants were allowed unlimited time to make responses, but were encouraged to produce verbs as quickly as possible.

Method

Participants. Ten Stanford University students participated for credit toward an introductory psychology course requirement or for pay. All participants in this and the other experiments provided informed consent and had native speaker-level English fluency (except for the bilingual participants in Experiment 6).

Materials. The stimuli consisted of two different noun lists of 40 words each (lists 1 and 2 in Appendix A) that were used by Raichle et al. (1994). Ambiguous words (e.g., saw–saw) and nouns that tend to generate the same verb (e.g., fork–eat, food–eat) were avoided (R. Buckner, personal communication). The experiment consisted of seven blocks of 40 trials each. The same noun list (repeated list) was used for Blocks 1–6, with the nouns presented in a different random order in each block. In Block 7, the other, novel, list of nouns was presented. Noun lists 1 and 2 were counterbalanced as repeated and novel items across participants.

Procedure. Participants were asked to generate an appropriate verb for each noun presented to them on the computer screen. An appropriate verb was defined as one which is related to the noun that appears on the screen; that is, one that describes what the presented noun might do or what it might be used for. Participants were instructed to generate the verbs as quickly as possible, without worrying about the quality or novelty of the chosen verb. Participants were not informed that the nouns might be repeated.

At the start of each block, the word READY appeared in the center of the screen. For each trial, a noun was presented in the center of screen and remained there until the microphone recorded a response. All reaction times were recorded using a Macintosh LC III computer system running Psychlab software. A voice key gated by the amplitude of a microphone input was used to measure voice onset times. The verb generated was written down by the experimenter and recorded onto a cassette tape to allow the experimenter to check the accuracy of the verbs recorded. When the voice key was triggered, the display was cleared and the next noun was presented 175 ms later. Participants received a short break (approximately 10 s in duration) between blocks.

At the end of the experiment, participants completed a debriefing questionnaire. Participants were asked if they were aware that some of the nouns were repeated, if they deliberately responded with the same verbs repeatedly, and if the task became easier as the experiment progressed.

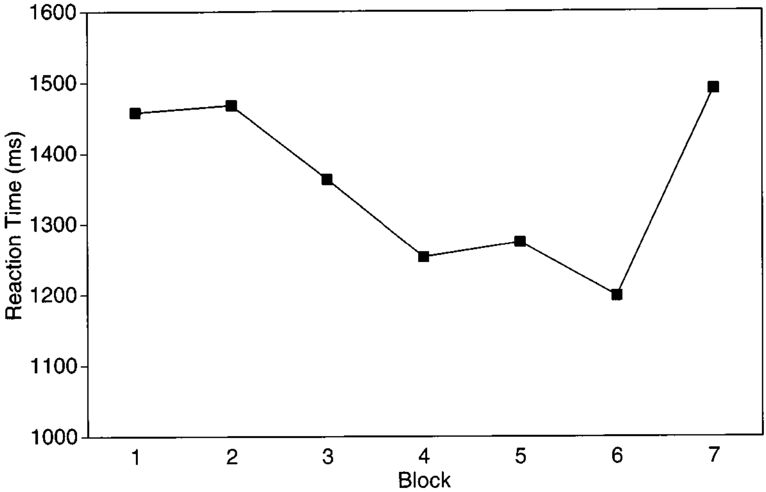

FIG. 1. Median verb generation times by block.

Results and Discussion

For each participant, median reaction times were calculated for each block (Fig. 1). In this and other experiments presented here, trials on which the voice key was triggered accidentally were eliminated from the analysis; in this experiment 1.3% of trials were disregarded.

Participants generated verbs for repeated nouns more quickly across Blocks 1–6, $F(5, 45) = 4.95$, $MS_e = 139029$, $p < .01$. Verb generation to novel nouns was slower in Block 7 than Block 6, $t(9) = 4.38$, $p < .01$, and no different than in Block 1, $t < 1.0$. These results replicate those of Raichle et al. (1994), indicating that allowing participants unlimited time to make responses, rather than having a fixed intertrial interval, did not change the pattern of results. In the present study, the median verb generation times were between 1000 and 1400 ms, so the *de facto* intertrial interval was comparable to the 1500-ms intertrial interval used by Raichle et al. (1994).

Raichle et al. (1994) reported that the average participant developed a stereotyped response (a verb repeated in at least 6 of the 10 practiced blocks) for 36 of 40 nouns, indicating a high verb repetition rate. In this experiment, verbs on each block were classified as repeated (previously generated as a response to that noun) or novel. The repeated verb generation rate was 82, 88, 94, 95, and 96% in Blocks 2 through 6, respectively. In Block 7 (novel noun block), 60% of verb generated by participants were repetitions of verbs generated in Blocks 1–6.

When asked about their awareness of repeated words, all 10 participants were aware that some or all of the words repeated throughout the first six blocks. Six participants indicated that they did not deliberately generate either repeated or novel nouns. One participant reported deliberately trying to generate the same verbs throughout the experiment; 3 other participants reported sometimes trying to generate novel verbs. However, participants who reported trying to generate novel nouns did not in fact have a lower verb repetition rate than participants who did not report such a strategy. Nine of the participants indicated that the task became easier as it progressed.

EXPERIMENT 2

In the verb generation task, only the nouns are manipulated experimentally; participants usually, but not always, generate the same verb when presented with a repeated noun. Raichle et al. (1994) reported that the average participant developed a stereotyped response (a verb repeated in at least 6 of the 10 practiced blocks) for 36 of 40 nouns and accordingly assumed that learning was of particular noun–verb pairs. However, verb generation priming could have three different bases: (a) the repeated presentation of a specific *noun*, (b) the repeated generation of a specific *verb*, or (c) the repeated generation of a specific *verb* to a specific *noun*. The goal of Experiment 2 was to discover which of these mechanisms mediates verb generation priming.

Method

Participants. Twenty Stanford University students and people recruited from the Stanford community participated in this experiment for class credit or pay.

Materials. Two matched 20-noun lists were created such that each list contained a noun likely to elicit a common verb (Appendix B). For example, the word ‘‘helmet’’ on one list was matched to ‘‘shirt’’ on the other list because participants tended to generate the verb ‘‘wear’’ for both of these nouns. In addition, a single list of 40 filler nouns was selected on the basis of being unlikely to elicit the same verb as any noun on the matched lists or any other noun on the filler list.

Procedure. The experiment consisted of four Blocks. Participants were given the same instructions as those in Experiment 1. Blocks 1–3 were repeated blocks in which the same 40 nouns were presented, in a different random order each time. Of the 40 nouns, 20 were from one of the matched lists and 20 were from the filler list. Block 4 was a novel block; the 40 nouns that were presented were taken from the other matched list and the remaining 20 filler nouns. Assignment of the matched lists and filler nouns to repeated and novel blocks was counterbalanced across participants. Matched list words were mixed with filler words in the hope that participants would produce roughly half repeated and half novel verbs to the Block 4 novel nouns.

Results and Discussion

Median reaction times per block were calculated as in the previous experiment and shown in Fig. 2. For each participant, each verb generated in Blocks 2–4 was classified as being a repeated or a novel verb, without regard to whether the noun was from the mixed list or the filler list. For Block 2, a verb was considered repeated if it had been produced in Block 1, regardless

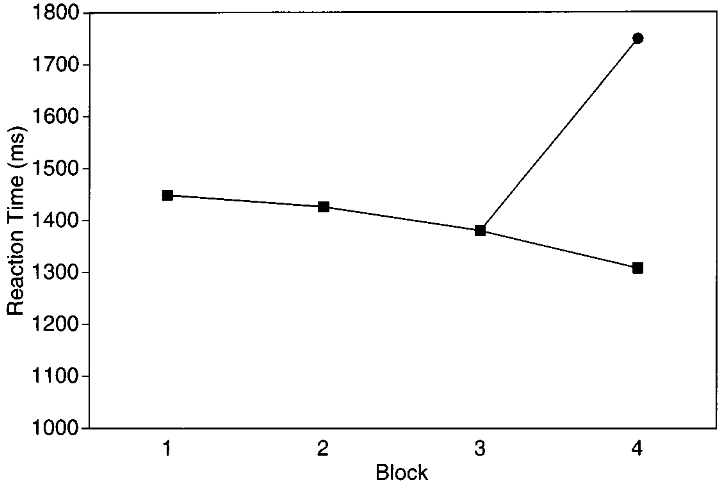

FIG. 2. Median verb generation times by block; in Block 4, repeated (square) and novel verbs (circle) are represented separately.

of whether it was generated in response to the same noun. For Block 3, the verb was categorized as repeated if it was produced in either or both of Blocks 1 and 2, again regardless of the stimulus noun. For Block 4, in which all nouns were novel, a verb was categorized as repeated if it was generated in two of the three preceding blocks, regardless of the noun to which it was generated. In Blocks 2, 3, and 4, 62, 77, and 46% of the verbs were classified as repeated, respectively.

The first analysis compared generation times for repeated and novel verbs in Blocks 2 and 3 (repeated noun blocks) in order to test whether priming was solely due to noun repetition. A 2 $\times$ 2 within-participants ANOVA with factors of verb repetition (repeated/novel) and Block (2/3) was performed. It should be noted that seven participants generated only 1 or 2 novel verbs on either Block 2 or Block 3; one participant had no novel items on Blocks 2 or 3, so that participant's data were excluded. There was a main effect of verb repetition such that repeated verbs were produced more quickly than novel verbs, $F(1, 17) = 35.6$, $MS_e = 4935558$, $p < .001$. There was no main effect of Block and no interaction between Block and verb repetition, Fs $<$ 1.0. Although there was no overall effect of Block, repeated verbs on these blocks were generated more quickly than verbs in Block 1, indicating facilitation in verb generation time for repeated verbs. The difference between Blocks 1 and 3 was significant, $t(19) = 2.20$, $p < .05$; the difference between Blocks 1 and 2 was nearly significant, $t(19) = 1.97$, $p = .06$.

In Blocks 2 and 3 all of the nouns were repeated; the difference in generation time between repeated and novel verbs indicates that priming is not solely due to noun repetition. Generation times for repeated and novel verbs were compared in Block 4, which consisted of novel nouns. As shown in Fig. 2, repeated verbs were generated significantly faster than novel verbs, $t(19) = 5.58$, $p < .001$. Because all of the nouns in Block 4 were novel, the difference between repeated and novel verbs in this block can only be due to verb repetition, not noun repetition or noun–verb paired learning. However, it is possible that noun repetition could have contributed to priming in Blocks 2 and 3. In order to examine this possibility, generation times for repeated verbs on Block 3 (repeated nouns) were compared to generation times for repeated verbs on Block 4 (novel nouns) to see whether there was a cost in generation time for shifting from repeated to novel nouns. Block 3 ($M = 1299$ ms) and Block 4 ($M = 1308$ ms) repeated verb generation times did not differ, $t < 1.0$, indicating no cost in shifting to novel nouns. This is further evidence that priming is verb-specific and independent of noun identity. In conclusion, the locus of priming in the verb generation task is the repeated generation of the verb, not the repetition of the noun or a particular noun–verb pairing.

EXPERIMENT 3

Experiment 3 examined whether it is necessary for participants to speak the generated verb for verb generation priming to occur. Research in other priming tasks such as primed picture naming indicates that priming is independent of articulation of a response (Wheeldon & Monsell, 1992); motor skill learning research has shown that learning is independent of particular motor effector systems (Cohen et al., 1990; Keele et al., 1995). Therefore, one might expect that verb generation priming would be independent of verb articulation. However, several neuroimaging studies of unprimed verb generation have found differences in brain activation when participants responded overtly, with vocalization, versus covertly, without vocalization. Participants who made overt responses showed activation in the left inferior prefrontal area, whereas those who made covert responses did not (McCarthy et al., 1993, and Wise et al., 1991, found no activation in left inferior prefrontal areas, but did find activation of a more posterior frontal lobe region). These studies indicate that overt and covert responding may lead to cognitive processing that differs by more than just speech production.

Experiment 3 compared two groups of participants. In one group, participants performed overt verb generation as in the preceding experiments: for each noun they generated and spoke aloud the first related verb they thought of. In the other group, participants were told to mentally generate a verb, but rather than speak, to press a button when they had a verb in mind. Thus, these participants made overt manual responses, but covert verb generation.

Method

Participants. Thirty-six Stanford University students and people recruited from the Stanford community participated in this experiment.

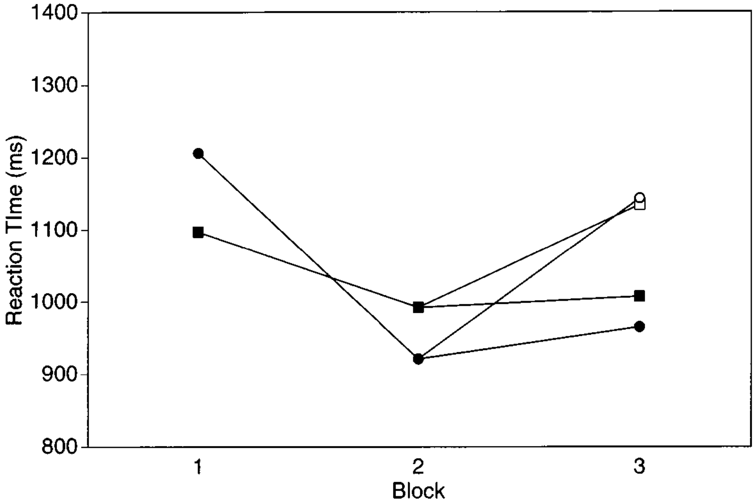

FIG. 3. Median generation times in the covert (circles) and overt (squares) conditions; in Block 3, repeated (closed symbols) and novel verbs (open symbols) are represented separately.

Materials. The stimuli for Experiment 3 consisted of a set of 60 nouns and a corresponding set of 60 verbs (Appendix C). The nouns were randomly divided into two sublists of 30 nouns each. The assignment of the sublists to serve as repeated and novel lists was counterbalanced across participants.

Procedure. Participants performed three blocks of verb generation, consisting of 30, 30, and 60 trials, respectively. Blocks 1 and 2 consisted of the repeated noun sublist, presented in a different random order in each block. Block 3 consisted of all 60 nouns, 30 seen twice earlier and 30 novel, presented in a random order.

Before testing, Overt participants were given standard verb generation instructions. Covert participants were given similar instructions, but were instructed to click the button on the computer mouse when they had generated a verb, rather than speak the verb aloud. All participants performed overt verb generation on the third block.

Results and Discussion

Median reaction times per block were calculated as in the previous experiments and are shown in Fig. 3. Response times for the first two blocks were analyzed in a mixed design ANOVA with a within-participants factor of Block (1/2) and a between-participants factor of generation response (Overt/Covert). Response times were faster in Block 2 than in Block 1, $F(1, 34) = 43.48$, $MS_e = 681723$, $p < .001$. There was no reliable difference between Overt and Covert response types, $F < 1.0$. Group and Block interacted, $F(1, 34) = 9.29$, $MS_e = 145620$, $p < .005$, such that Covert participants were somewhat slower than Overt participants in Block 1 but not in Block 2. In neither block was the difference between Covert and Overt significant, $t(34) = 1.41$, $p > .1$, and $t(34) = 1.1$, $p > .1$, respectively. Covert response participants performed a complex task that involved both generation and manual response, and they may have taken longer to become efficient at the manual response. However, both Overt and Covert groups showed a significant main effect of block, $t(17) = 2.77$, $p < .05$, and $t(17) = 6.28$, $p < .001$, respectively, indicating that priming from Block 1 to Block 2 occurred in both groups.

In Block 3, both groups of participants performed verb generation with an overt vocal response to a mixture of repeated and novel nouns. Overt participants generated verbs to the repeated nouns in Block 3 faster than they generated verbs to those nouns in Block 1, $t(17) = 4.94$, $p < .001$, but not faster than generation in Block 2, $t(17) = -1.11$, $p = .28$, implying that priming occurred, but did not increase when the noun was repeated more than once. A measure of verb generation facilitation was calculated for each participant by calculating the difference between median reaction times to novel nouns and repeated nouns. There was no difference in facilitation between participants who had previously responded verbally ($M = 127$ ms) and participants who had previously responded motorically ($M = 178$ ms), $t(34) = 1.3$, $p > .1$. In summary, verb generation facilitation is not dependent on overt articulation of the verb. This result is consistent with research showing that picture naming priming is independent of articulation (Wheeldon & Monsell, 1992). Thus, verb generation priming happens at or above the level of verb lexicalization prior to actual production; Experiments 4–6 explored whether priming occurs at a conceptual level.

EXPERIMENT 4

Conceptual priming tasks usually show greater priming if participants generate the primed item to a semantic cue than if participants read the primed item, presumably because such generation requires more conceptual processing than mere reading (Blaxton, 1992; Roediger & McDermott, 1993; Srinivas & Roediger, 1990). Experiment 4 examined whether generation of a verb is necessary for priming to occur by comparing generation with reading verbs and furthermore examined whether generation facilitates priming.

Experiments 4 and 5 incorporated methodological changes aimed at making the task more comparable with other conceptual priming tasks and at avoiding possible item effects. A two-block design was adopted, in which priming on the second block was a result of a single presentation of the verb in the first block. Most conceptual priming tasks use a two-block design, which has the advantage that priming in the second block can be attributed to a particular study instance rather than being due to multiple generations of the verb.

In Experiments 1 through 3, the nouns were under experimental control, but the generated verbs were not. This raises the possibility that priming may be due to specific item effects, in that participants may be more likely to repeatedly generate particular kinds of verbs. For example, a verb with a strong association with a noun could be both more likely to be repeatedly generated and generated more quickly than a verb with a weaker association. In Experiments 4 and 5, verbs are under experimental control: participants were primed for particular verbs through reading, and priming was measured on the following generation test.

On the first block of Experiment 4, participants generated verbs in response to nouns as in the previous experiments (Generate condition) or simply read a list of verbs associated with those nouns (Read condition). On the second block, all participants performed verb generation to novel noun stimuli. The nouns were selected so that half of them could be responded to appropriately with a verb from the first block, and half could not. If priming is specific to generation of a verb, then priming should be found in the Generate condition, but not in the Read condition. Alternatively, if reading the verb is sufficient to prime it for the verb generation task, participants in both conditions should show priming.

Method

Participants. Forty-eight[1] Stanford University students and people recruited from the Stanford community participated in this experiment, either for course credit or for pay.

Materials. The stimuli for Experiment 4 consisted of a set of 60 nouns and a corresponding set of 60 verbs (Appendix D). The verb and noun lists were formed by selecting nouns which usually elicited a consistent verb across participants in previous experiments. The verb and noun lists were divided into two matching 30-item priming lists for use in Block 1. The assignment of priming lists was counterbalanced across participants. One noun testing list for use in Block 2 was formed by randomizing the order of the 60 nouns.

Procedure. Generate condition participants were given standard verb generation instructions and then performed verb generation on one of the noun priming lists. Read condition participants were informed that they were going to be shown verbs and that they should read each verb aloud as quickly as possible. Read participants then were shown each of the verbs from one of the verb lists using the same presentation and response parameters as for noun presentation in this and the preceding experiments. In Block 2, all participants performed verb generation using the noun testing list.

Results and Discussion

Median verb generation times in Block 2 were calculated for repeated and novel verbs and are shown in Table 1. For the Read condition, a repeated verb was defined as one that was both presented in Block 1 and generated in Block 2; a novel verb was one that was neither presented in Block 1 nor generated earlier in Block 2. For the Generate condition, a repeated verb was defined as one that was generated by the participant in both Blocks 1 and 2 and, in addition, was a verb that was read by participants in the Read

[1] More participants were needed in this experiment and in Experiment 5 than in the other experiments due to the need to compare priming under different encoding conditions rather than merely examining whether priming occurred.

TABLE 1
Median Reaction Times on Block 2 as a Function of Priming Condition and Verb Repetition, Experiment 4

	Verb repetition				
	Repeated		Novel		
Priming condition	M	(SD)	M	(SD)	Difference
Read	1231	(243)	1392	(309)	160
Generate	1087	(189)	1275	(260)	188

condition. Overall, 85% of the verbs produced by participants in Block 1 of the Generate condition appeared on the verb list studied by the participants in the Read condition.

Median generation times for repeated and novel verbs were compared in a 2 × 2 ANOVA with between-participant factor of study condition (Read/Generate) and a within-participant factor of verb repetition (Repeated/Novel). Repeated verbs were generated more quickly than Novel verbs, $F(1, 46) = 61.81$, $MS_e = 726189$, $p < .001$. There was a trend toward a main effect of priming condition, such that Generate participants generated verbs more rapidly than Read participants, $F(1, 46) = 3.48$, $MS_e = 408791$, $p = .07$. The faster generation of Generate participants could be due to their having practiced the task in the first block or to perceptual repetition priming for half of the nouns. There was no interaction of repetition and study condition, $F < 1.0$, indicating that Read participants showed as much priming as Generate participants. In order to confirm that priming was found in the Read condition, the simple effect of repetition within the Read condition was calculated and was significant, $t(23) = 6.05$, $p < .001$. These results indicate that reading a verb aloud was sufficient cognitive processing to cause priming for the verb on the verb generation task and that the amount of priming in the Read and Generate conditions was not significantly different.

EXPERIMENT 5

The equivalent priming found after reading a verb aloud or generating a verb in Experiment 4 was surprising because conceptual priming tasks often show greater priming following generation than reading. Conceptual priming tasks also often show greater priming following deep (semantic) processing of items than shallow (orthographic or phonological) processing of items (Hamann, 1990; Srinivas & Roediger, 1990). Experiment 5 was designed to investigate whether such a levels of processing manipulation would have an effect on verb generation. In Experiment 5, all participants saw verbs in the study phase: Half of the participants performed a semantic judgment about the verbs (deep condition), and half performed an orthographic judgment

TABLE 2
Median Reaction Times on Block 2 as a Function of Priming Condition and Verb Repetition, Experiment 5

	Verb repetition				
	Repeated		Novel		
Priming condition	M	(SD)	M	(SD)	Difference
Deep	1107	(160)	1270	(236)	163
Shallow	1065	(142)	1166	(183)	101

(shallow condition). Following the study phase, all participants performed verb generation.

Method

Participants. Eighty Stanford University students and people recruited from the Stanford community participated in this experiment, either for course credit or for pay.

Materials. The stimuli for Experiment 5 were the same lists of nouns and verbs used in the Read condition of Experiment 4.

Procedure. Participants were informed that they were going to be presented with a verb and they should answer a question about the verb as quickly as possible. Deep condition participants were instructed to answer the question ‘‘Is this an activity that you would do in a typical week?’’ For example, if presented with the word ‘‘dream,’’ the appropriate response would be to say yes, and if presented with the word ‘‘drown,’’ the appropriate response would be to say no. Shallow condition participants were instructed to answer the question ‘‘Does this word contain the letter E?’’ Participants were then presented with one of the verb lists for Block 1. Study lists were counterbalanced across encoding conditions. On Block 2, all participants performed verb generation as in Experiment 4.

Results and Discussion

Median verb generation times were calculated for repeated and novel verbs as in the Read condition in Experiment 4 and are shown in Table 2. Generation times were compared in a 2×2 ANOVA with a between-participants factor of study condition (Deep/Shallow) and a within-participant factor of verb repetition (Repeated/Novel). Repeated verbs were generated more quickly than novel verbs, $F(1, 78) = 79.8$, $MS_e = 697818$, $p < .001$. There was a trend toward a main effect of group, such that Shallow participants generated verbs more rapidly than Deep participants, $F(1, 78) = 3.57$, $MS_e = 209924$, $p = .06$; the reason for this difference is unclear. There was a significant interaction between priming condition and verb repetition such that in the Deep condition there was a larger difference between repeated and novel verb generation time (i.e., there was more priming) than in the Shallow condition, $F(1, 78) = 4.31$, $MS_e = 37684$, $p < .05$. This result is consistent with research in other conceptual priming tasks that found that deep processing leads to more priming than shallow processing (Hamann, 1990; Srinivas & Roediger, 1990). In order to confirm that priming was found in the Shallow condition, the simple effect of repetition within the Shallow condition was calculated and was significant, $t(39) = 5.9$, $p < 0.001$.

EXPERIMENT 6

Experiment 6 was designed to further explore the conceptual nature of verb generation priming by investigating whether priming transfers across languages. Transfer across languages indicates that priming does not happen at a perceptual level, because the perceptual forms of words differ across languages or at a lexical level to the extent that translation equivalents in different languages have separate lexical representations.

One of the differences between perceptual and conceptual priming is in the degree to which priming is dependent on integrity of the perceptual form of the stimulus; according to this distinction, priming should not cross languages for orthographically different translation equivalents on perceptual tasks, but could do so for conceptual tasks. Most cross-language priming research has used the word fragment completion task, which is primarily a test of perceptual repetition priming. These studies find within-language priming but very little cross-language priming (Durgunoglu & Roediger, 1987; Watkins & Peynircioglu, 1983), except when participants perform a lengthy or conceptually elaborative task during initial encoding (Smith, 1991; Basden et al., 1994).

Cross-language transfer has not been examined in conceptual priming tasks such as category exemplar priming or word association priming, but it has been examined in picture naming priming tasks. Several studies show that picture naming involves lexical or conceptual processing (Glaser, 1992; Levelt et al., 1991; Wheeldon & Monsell, 1992), and priming due to repeated picture naming includes a nonperceptual (lexical or conceptual) component (Park & Gabrieli, 1995). The cross-language results have been inconsistent. Monsell et al. (1992) studied bilingual Welsh–English speakers and found that naming to definition primed later picture naming latency within a language, but only primed across languages when the phonological form of the word was similar in both languages; thus, there was no conceptual cross-language transfer. On the other hand, Sholl et al. (1995) found transfer between picture naming in either language and translation for words from bilinguals' first language to their second language (which they argue is conceptually mediated) but not between second language and first language (which they argue is lexically mediated).

In should be noted that in standard semantic priming experiments (e.g., reading ''nurse'' primes for reading ''doctor'') translation equivalents prime each other when the latency is short, but when latency is long there is only repetition priming between words within a language (Keatley et al., 1994).

However, semantic priming effects are short-lived and semantic priming is not considered a form of long-term conceptual priming (Roediger & McDermott, 1993). Verb generation priming should provide a better indication of whether long-term conceptual priming crosses language boundaries. Research on language representation in bilinguals indicates that common brain locations are active when semantic tasks are performed in each language, including verb generation (Klein et al., 1995) and abstract/concrete judgments (Wagner et al., 1996). These results indicate that the initial semantic activation does not differ across languages.

Method

Participants. Twelve Spanish–English bilinguals and 12 monolingual English speakers participated in this experiment; they were Stanford University students or other members of the Stanford community and participated either for course credit or for pay. For 11 of the 12 bilingual participants, Spanish was their first language and they learned English in elementary school. The remaining participant spoke four languages; her native languages were Farsi and French and she learned English in childhood and Spanish in adolescence.

Materials. Two lists of 30 nouns were prepared in both Spanish and English versions (Appendix E). Nouns were chosen from those used in previous experiments on the basis that they were associated with a unique verb in both languages.

Procedure. The experiment consisted of four blocks of verb generation: in three blocks the repeated list was presented, and in the final block the repeated and novel word lists were combined and presented in a random order. Assignment of word lists to repeated and novel roles was counterbalanced across participants. Bilingual participants performed the first three blocks in Spanish and Block 4 in English. Control participants performed the experiment throughout in English. Otherwise, all participants were given the same instructions as in Experiment 1.

Results and Discussion

Words generated in Block 4 were classified as repeated or novel, using the criterion that a repeated verb was one that had been generated (or its translation equivalent generated) in two of the three repeated blocks. Overall, 50% of verbs in Block 4 were repeated for the bilingual group and 52% for control participants. Therefore, changing languages did not change the frequency with which participants generated repeated verbs.

Median reaction times were calculated for each block for the bilingual and monolingual participants and are shown in Fig. 4; scores were calculated separately for repeated and novel verbs in Block 4. Generation time across the first three blocks was examined in a 2×3 ANOVA, with a between-participants factor of participant group (bilingual/monolingual) and a within-participants factor of Block (1–3). There was a main effect of participant group, such that monolingual participants generated verbs more slowly than bilingual participants, $F(1, 21) = 8.06$, $MS_e = 1486605$, $p < .01$. There was also a main effect of Block, $F(2, 42) = 4.44$, $MS_e = 168463$, $p < .05$. There was no participant group by Block interaction, indicating that both groups showed similar facilitation of verb generation across blocks.

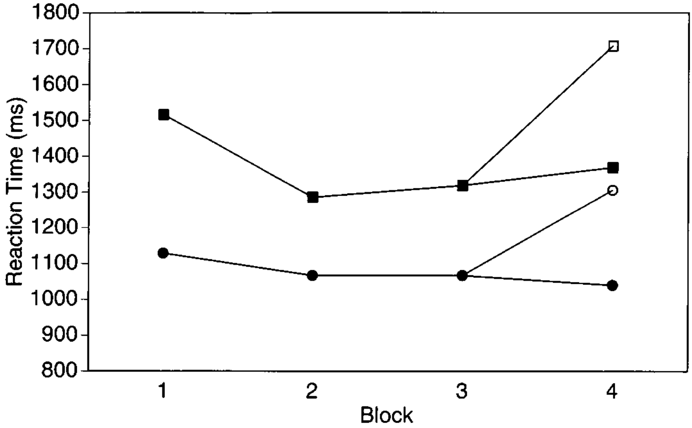

FIG. 4. Median verb generation times in the bilingual (square) and monolingual (circle) conditions; in Block 5, repeated (closed symbols) and novel verbs (open symbols) are represented separately.

Priming was examined in Block 4 using a 2 × 2 ANOVA, with a between-participants factor of participant group (bilingual/monolingual) and a within-participant factor of repetition (repeated/novel). There was a main effect of participant group, such that bilinguals generated verbs more slowly than monolinguals, $F(1, 22) = 7.72$, $MS_e = 1593048$, $p < .05$. This may be due to bilinguals having longer word access times than monolinguals or to bilinguals adjusting to the change in language. There was also a main effect of repetition, such that repeated verbs were generated more quickly than novel verbs, $F(1, 22) = 32.60$, $MS_e = 1094599$, $p < .001$. There was no interaction, indicating that cross-language priming ($M = 338$ ms) was as great as within-language priming ($M = 266$ ms), $F < 1.0$.

In conclusion, verb generation priming completely transfers across languages in bilinguals. This is further evidence that verb generation priming is due to conceptual priming rather than perceptual, motor, or lexical priming. These results are consistent with the work of Sholl et al. (1995), who demonstrated cross-language conceptual priming on a word translation task after picture naming. In Experiment 6, bilingual participants transferred from their first language (Spanish) to their second language (English), and thus the finding that conceptual priming transfer occurred is consistent with Sholl et al.'s (1995) argument that links from words in the bilingual's first language to words in the second language are conceptual in nature.

GENERAL DISCUSSION

Several important features of verb generation priming were discovered in these experiments. Verb generation priming is specific to the verb response and independent of the noun stimulus eliciting the response. Verbs can be primed via routes other than generation, such as reading and making judgments about the verbs. Finally, verb generation priming transfers across languages, indicating that the priming in this task is not due to perceptual or lexical features particular to a language, but rather involves semantic processes common to all languages spoken.

One puzzling aspect of these experiments was the discrepancy across experiments in magnitude between priming as measured by generation time decrease across blocks of repeated nouns, versus priming as measured by differences in reaction times for novel and repeated verbs on the novel noun block. Overall, generation time decreases across blocks of repeated nouns were substantial, between 50 and 200 ms, similar to the magnitude of priming found in picture naming tasks. However, they were modest in comparison to differences in generation time in the novel noun block for repeated and novel verbs, which were between 250 and 450 ms. This pattern of results implies that there may be some interference in the production of a novel verb in the final block, in addition to facilitation for the production of a repeated verb.

Verb Generation as a Conceptual Priming Task

Verb generation was hypothesized to be a conceptual priming task because the response requires accessing the meaning of the stimulus and because the neural activations in verb generation were similar to those in other conceptual processing tasks (Blaxton et al. 1996; Gabrieli et al., 1996). Furthermore, verb generation priming is preserved in amnesia (Seger et al., 1997b), as are many conceptual tasks, including category exemplar priming and word association priming.

Roediger and McDermott (1993) argued that conceptual priming should be independent of the physical form of the stimuli; verb generation priming clearly meets this criterion because priming for a verb (e.g., ring) completely transfers across nouns (e.g., from telephone to bell). Experiments 4 and 5 investigated whether verb generation had two additional properties that Roediger and McDermott argued were characteristic of conceptual priming: greater priming after generating than reading and greater priming after semantic than orthographic encoding. Priming in verb generation was enhanced by semantic relative to orthographic encoding, but it was similar after generating or reading verbs. Verb generation is the first task that demonstrates a dissociation between read/generate and levels of processing manipulations of conceptual encoding.

Why might a conceptual task be affected differently by a read/generate manipulation than a levels of processing manipulation? One possibility is that reading and orthographic judgments may not involve the same degree of semantic processing. Reading a word allows a participant to perform full processing of the word, including whatever semantic processing automatically is performed in the course of reading. Making an orthographic decision about a word, on the other hand, discourages participants from fully reading the verb and encourages them to ignore word identity in favor of devoting processing resources to identifying the particular perceptual feature of the word being queried. In this sense, performing an orthographic judgment is similar to reading a word under conditions of divided attention. On the other hand, generating the verb rather than reading it might increase the amount of semantic processing performed, but in the read condition a basic amount of processing is still performed. Reading, generating, and semantic, and orthographic processing may involve at least three levels of semantic processing rather than just two levels: impoverished processing, standard processing, and enhanced processing. Conceptual priming tasks may differ from each other in that for some tasks, like verb generation, standard semantic processing is necessary and sufficient for full priming, whereas for other tasks, such as category exemplar priming, enhanced semantic processing increases priming above the level seen with standard processing.

For some tasks, even impoverished semantic processing may be sufficient to subserve full priming. Vaidya et al. (1997) found that one group of conceptual priming tasks was affected by a levels of processing manipulation (category exemplar priming and word association priming with weak associates). Performance on these tasks required standard semantic processing. Other conceptual priming tasks were not affected by the levels of processing manipulation (category verification priming, abstract/concrete judgment priming, and word association priming for strong associates). Impoverished processing was sufficient for priming to occur on these tasks. Vaidya et al. argued that in tasks affected by the levels of processing manipulation, the cue presented at test completely guides retrieval of all relevant conceptual knowledge. In tasks unaffected by levels of processing manipulations, the cue presented at test specifies semantic criteria for retrieval of conceptual knowledge, but there are numerous possible retrieval alternatives. Thus, in tasks in which the cue completely guides retrieval, priming may be sufficiently subserved by impoverished semantic processing, whereas in tasks which have multiple response options, priming may require at least standard semantic processing. In verb generation priming each noun has multiple possible verb responses; it is consistent with Vaidya et al.'s results that verb generation priming is affected by the levels of processing manipulation.

Is Verb Generation Implicit?

One of the reasons priming tasks have been of such great interest to cognitive psychologists is that often performance is independent of participants' conscious awareness of learning and memory retrieval. For this reason, these tasks are often termed implicit memory tasks. It is reasonable to ask whether the verb generation task is an implicit memory task in this sense. Participants' responses to the debriefing questionnaires showed that participants in these experiments were aware of both the repeating nature of the nouns and their own tendency to repeat verbs. Although some participants reported that they tried consciously to either repeat or not repeat verbs, most often participants claimed that the tendency to retrieve repeated verbs was not intentional. Regardless of their intentions, however, participants were aware of many aspects of the task. In order to determine whether repeated verb generation facilitation is implicit in the sense of being independent of conscious awareness, it will be necessary to experimentally interfere with awareness without eliminating verb generation facilitation.

An alternative definition of implicit is based on the brain areas necessary for performing the task, rather than on the conscious or unconscious nature of the task. The implicit–explicit memory distinction has been remarkably well reflected in the pattern of preserved and impaired memory performance seen in patients with global amnesia. Patients with amnesia often show preserved performance on perceptual and conceptual priming tasks, implying that these tasks are not subserved by the hippocampal and diencephalic structures impaired in amnesia. Amnesic patients show preserved verb generation priming, coupled with impaired recognition for the nouns used in the experiment (Seger et al., 1997b). The amnesic patients' intact priming indicates that verb generation priming occurs independently of explicit memory mechanisms.

Implications for Theories of Automaticity and Verbal Response Selection

A main conclusion of the experiments presented here is that verb generation is not specific to a particular noun or noun–verb combination, but rather a more general word activation effect specific to retrieval of a verb. The retrieval can be externally (reading) or internally (generation) guided, can be overt or covert, and can occur in one or another language. The results of the experiments presented here can constrain theories of verbal response production in that theories should be able to account for the following properties of response production tasks: First, once a response is accessed, it can be applied to stimuli more quickly than responses that are not currently active. Second, response priming is response-specific, independent of stimulus identity. Third, responses can be activated through varied tasks, which lead to priming on the response production task. For example, in Experiments 4 and 5, responses were activated by reading and then were applied in the generation task.

Gullapalli et al. (1995) developed a model for categorical verbal responses to words that involved two processes, controlled and automatic. The controlled process searches a semantic store for an appropriate response, whereas the automatic process is a linear associative network linking together stimulus words and responses. They theorized that in the brain, the automatic stream depends on the sylvian-insular cortex, which is active during verb generation to a repeated set of nouns (Raichle et al., 1994). Their model accounts for the first and third properties outlined above: responses can be made active and through a variety of routes. However, one feature of their model is that it assumes a pairing between a stimulus word and a response word, which would imply that any change in the stimulus word would eliminate priming of the response. This prediction is not consistent with the experiments in this paper that show priming independent of stimulus word identity.

The differences between novel items and practiced items may reflect a shift from using controlled mechanisms to using automatic mechanisms (Schneider & Shiffrin, 1977). Raichle et al. (1994) framed their results as showing a change in brain areas active when a task becomes automatic and interpreted their results as supporting Logan's (1992) instance theory of automaticity. Logan's theory was designed to account for results from experimental paradigms such as mental arithmetic in which participants begin by producing responses through an iterative mental process and later shift to directly recalling responses from memory. However, the experiments presented here indicate that verb generation does not fit the class of tasks that the instance theory can account for. First, the original access of the verb does not involve an iterative application of a mentally held algorithm. Second, facilitation of a particular verb is not dependent on its being generated in response to a particular noun in verb generation, whereas Logan's theory depends on the relationship between stimulus and response being invariant so that it can be stored in and recalled from memory.

In conclusion, the research presented here indicates that verb generation priming is amenable to behavioral research as well as functional imaging. These research methodologies can converge and provide the basis for a deeper understanding of conceptually linked response generation and memory.

APPENDIX A: WORD LISTS USED IN EXPERIMENT 1

List 1. basket, bed, bee, beer, blanket, boat, brick, broom, chair, crayon, dog, fire, fist, food, foot, glove, gun, horn, hose, ice, job, key, lens, letter, match, money, needle, oven, paper, phone, pill, plane, pool, purse, razor, scale, school, soap, toy, tree.

List 2. ball, baton, bell, bench, bike, book, cane, car, cat, cigar, doll, dollar, door, fan, finger, flag, fork, gift, grave, gum, hammer, jet, knife, ladder, lake, lawn, milk, movie, oar, pen, radio, rifle, ruler, seed, shirt, song, stove, towel, wheel, yarn

APPENDIX B: Word Lists Used in Experiment 2

Matched Lists

List 1 noun	List 2 noun	Common verb
toddle	ant	crawl
moon	sun	shine
telephone	bell	ring
movie	television	watch
food	dinner	eat
helmet	shirt	wear
beer	soda	drink
bird	airplane	fly
baseball	frisbee	throw
pipe	cigar	smoke
chair	bench	sit
door	window	open
chorus	song	sing
pencil	chalk	write
guitar	piano	play
newspaper	book	read
lens	eye	see
paycheck	money	spend
schoolbus	bike	ride
music	radio	listen

Filler Nouns

oven, broom, dog, key, blanket, needle, fist, brick, pool, razor, ice, scale, hose, soap, wheel, boat, gift, foot, flag, seed, disk, ruler, pig, towel, gum, hammer, finger, tail, cat, heart, baton, rifle, cane, wind, bone, coach, museum, secret, snow, house.

APPENDIX C: Word Lists Used in Experiment 3

Noun	Corresponding verb
razor	shave
shovel	dig
tears	cry
chair	sit
telephone	call
tail	wag
charity	give
chef	cook
wind	blow
gum	chew
shirt	wear

APPENDIX C—*Continued*

Noun	Corresponding verb
newspaper	read
pool	swim
baton	twirl
joke	laugh
door	open
bed	sleep
bridge	cross
frisbee	throw
pencil	write
foot	walk
scissors	cut
hammer	hit
sun	shine
song	sing
cigar	smoke
airplane	fly
ant	crawl
mountain	climb
hair	comb
car	drive
fire	burn
secret	tell
piano	play
lawn	mow
ice	melt
suitcase	pack
perfume	smell
heart	beat
oar	row
television	watch
volcano	erupt
broom	sweep
lollipop	lick
problem	solve
eye	see
milk	drink
blanket	cover
pills	take
finger	point
towel	dry
scale	weigh
rifle	shoot
toll	pay
itch	scratch
dog	bark
student	study
bell	ring
dice	roll
pendulum	swing

APPENDIX D: Word Lists Used in Experiments 4 and 5

Noun	Corresponding verb
razor	shave
shovel	dig
tears	cry
oven	bake
basket	carry
chair	sit
telephone	call
ear	hear
music	listen
seed	plant
tail	wag
charity	give
chef	cook
wind	blow
flag	wave
gum	chew
shirt	wear
newspaper	read
pool	swim
money	spend
baton	twirl
joke	laugh
key	unlock
door	open
bed	sleep
bridge	cross
frisbee	throw
pencil	write
foot	walk
ant	crawl
scissors	cut
hammer	hit
sun	shine
church	pray
mountain	climb
hair	comb
airplane	fly
song	sing
cigar	smoke
suitcase	pack
car	drive
secret	tell
ice	melt
fork	eat
bee	buzz
television	watch
fire	burn

APPENDIX D—*Continued*

Noun	Corresponding verb
house	live
heart	beat
milk	drink
lollipop	lick
bell	ring
piano	play
potato	peel
rifle	shoot
horn	honk
duck	quack
eye	see
scale	weigh
broom	sweep

APPENDIX E: Word Lists Used in Experiment 6

Spanish	English
cabeza	head
martillo	hammer
horno	oven
dedo	finger
toalla	towel
cerveza	beer
pala	shovel
perro	dog
dinero	money
avion	airplane
fuego	fire
maleta	suitcase
hielo	ice
libro	book
pelo	hair
telefono	telephone
periodico	newspaper
montana	mountain
flor	flower
cama	bed
coche	car
puente	bridge
huevo	egg
palo	broom
piscina	pool
atleta	athlete
jabon	soap
pistola	rifle

APPENDIX E—*Continued*

Spanish	English
navaja	razor
tijeras	scissors
cantaro	pitcher
escuela	school
sol	sun
cigarillo	cigarette
musica	music
camisa	shirt
camara	camera
comida	food
lagrima	tears
corazon	heart
cuento	story
enfermedad	disease
lapiz	pencil
semilla	seed
viento	wind
regalo	gift
puerta	door
pie	foot
escala	scale
chicle	gum
pelicula	movie
sobre	envelope
volcan	volcano
misterio	mystery
cancion	song
pildora	pills
chiste	joke
juego	game
lluvia	rain
silla	chair

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