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TRANSPARENCY AND HEADEDNESS IN PROCESSING COMPOUND WORDS: A LEXICAL DECISION STUDY

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ABSTRACT

In this study, we investigate the effects of lexical transparency and headedness on English compound word processing. Previous research involving semantic priming of compounds suggests that individual constituents of at least partially transparent compound words are activated during processing (e.g. Jarema, Busson, Nikolova, Tsapkini, & Libben, 1999; Sandra, 1990). We hypothesized that in a lexical decision task, subjects would show faster average response times to compound words when primed by a word related to one constituent, especially a transparent or head constituent. Our results are generally consistent with previous studies in that response times are faster for transparent compounds paired with related words than with unrelated word pairs, with some exceptions for transparent compounds. Our results offer support for constituent activation during compound word processing and morpheme-based lexical organization.

Keywords: Compound Words, Spreading Activation, Lexical Decision Task (LDT), Transparency, Headedness

1.0 Introduction

Linguists and cognitive psychologists have many outstanding questions about how individual words are organized and accessed in the mental lexicons. Lexical entries might correspond to individual words. Alternatively, lexical representations could correspond to morphemes, and multiple lexical entries could combine to create one word. This would mean that multimorphemic words, like *surprised,* are formed from two entries, such as *surprise* and *-ed*. Organizing lexical entries by morpheme would reduce the total number of representations that must be contained in the lexicon, while also representing the relationship between simple words like *surprise* and morphologically complex words like *surprised*.

It is unclear, however, how compound words are represented in the mental lexicon. Compound words, such as *oatmeal*, are formed by two morphemes that speakers consider independent words. Each morpheme in a compound, called a constituent, should have an individual lexical entry independent of the compound word. The compound word as a whole, though, might be represented only by its constituents (morpheme-based representation) or by a separate lexical entry (word-based representation). Having a better understanding of the mental representations of compound words would provide more information about the structure of the lexicon and potentially about the ways we access lexical entries as we process language. In order to explore this issue, we performed a lexical decision experiment using compound words. The results of this study offer support for morpheme-based lexical organization of certain types of compound words. We explore this issue in this paper, which is organized as follows: Section 2 provides a discussion of previous studies. Section 3 explains the methodology used in our experiment. Section 4 contains experimental results, and finally, in Section 5, we discuss these results, as well as the implications and limitations of our study.

[1] **Authorship Responsibilities:** Author 1 and Author 2 share equally the rights, privileges, and responsibilities of this publication.

2.0 Literature Review

Many past studies have investigated the representation and processing of compound words. Several of them have used a lexical decision task, in which subjects are shown letter sequences and must indicate whether the sequences form words or not. They use this method to examine whether a word's constituents are accessed, or activated, in the processing of compound words. Results of these experiments show that when English, French, Bulgarian, and Dutch compound words are processed, constituents are activated individually (Jarema, Busson, Nikolova, Tsapkini, & Libben, 1999; Ji, Gagné, & Spalding, 2011; Libben, Gibson, Yoon, & Sandra, 2003; Sandra, 1990). MacGregor and Shtyrov (2013) investigated constituent activation in an electroencephalogram (EEG) study measuring auditory Mismatch Negativity, a brain response to auditory input that shows different patterns in response to single lexical entries than it shows to syntactic strings made of multiple lexical entries. Activation patterns for transparent compound words (defined in the next paragraph) were similar to those of syntactic strings.

A compound word's **transparency** is based on the clarity of the relationship between the meaning of the word's constituents and the meaning of the word as a whole. In fully transparent compound words, such as *notebook*, these meanings are obviously related. When the relationship between constituent and compound word meaning is neither obvious nor clear, as in *hogwash* (meaning "nonsense"), the compound word is considered completely **opaque**. Compound words may also be **partially opaque**, as in *butterfly*, where one constituent (*fly*) has a meaning associated with the meaning of the whole compound word, but one constituent (*butter*) has a meaning that is not related to the meaning of the whole word. Sandra (1990) demonstrated that Dutch transparent compound words show individual constituent activation through decreased response times to transparent compounds following semantic primes related to one constituent. Jarema et al. (1999) replicated these results with French and Bulgarian compound words, and also found that partially opaque compounds displayed a similar pattern of activation of individual constituents. In contrast, results of Sandra (1990) and MacGregor and Shtyrov (2013) suggested that processing completely opaque compound words does not involve constituent activation. These results indicate that not all compound words are processed the same way, and a compound word's level of transparency can affect which way it is processed.

Another factor that influences how compound words are processed is **headedness**. A compound word's head is the constituent that determines the word's part of speech, and in English the head is always the rightmost constituent. For example, in the compound word *blackboard*, *board* is the head, because a "blackboard" is a noun like *board* and not an adjective like *black*. Jarema et al. (1999) showed that the head of a compound word is activated to a greater extent than its other constituent. French compound words, which may be either right-headed (e.g. *grasse matinée* ''sleep in'') or left-headed (e.g. *garçon manqué* "tomboy"), showed a consistent pattern that indicated greater activation for the head than for the nonhead in both the right and left positions, indicating that this effect is from the head and not the right constituent.

Many previous studies have relied on lexical decision tasks to provide information about activation of constituents in compound words. In a lexical decision task, the time it takes subjects to decide whether or not a sequence is a word is affected by semantic priming. If subjects see a prime word that is semantically related to the target word that follows, they respond more quickly.

In an early lexical decision experiment done by Meyer and Schvaneveldt (1971), researchers found that priming a target word with a semantically related paired word decreased response time. In this study, participants viewed associated words (e.g. NURSE and DOCTOR) subjects responded more quickly on average than they did when viewing two unassociated words (e.g. NURSE and BREAD) or a pair that included a non-word letter sequence (e.g. MARB).

Meyer and Schvaneveldt (1971) suggested that if words were "organized semantically" in memory, with associated words close to one another, faster response times for associated words might be explained by a spreading-excitation model. This would mean that when one word was retrieved and therefore excited, nearby semantically-associated words would also become excited. As a result, these words would need less extra excitement during later retrieval, so they could be retrieved more easily and quickly. This spreading-excitation model is similar to spreading activation theories within hierarchical network and connectionist models of semantic memory (Galotti, 2018). Under spreading activation theory, faster response times in trials which use semantic priming are the result of higher activation of the target word due to extra activation it receives from its associated semantic prime. Compound word lexical decision studies often prime one individual constituent of the compound, and then measure the response time for the compound word as a whole. If response time for the compound word is faster in this condition than unprimed conditions, this is thought to be a product of individual constituent activation, because it shows that subjects are sensitive to a prime for one distinct constituent while processing the compound word.

In our study, we run a lexical decision task modeled on Meyer and Schvaneveldt (1971) to further investigate how compound words are stored in the lexicon and how transparency and headedness affect compound word processing. Based on the hypothesis that constituent activation occurs only in transparent and partially opaque compound words, we predicted that for these types of compound words, priming one individual constituent would result in faster response times than pairing compound words with unrelated words. We also predicted that since compound words with relatively high levels of transparency have been argued to show greater constituent activation, we would see a greater effect from semantic priming on transparent compounds than on partially opaque compounds. Finally, our third prediction was that response times would be affected by headedness, with lower response times when stimuli were paired with words associated with head constituents than words associated with nonhead constituents.

3.0 Method, Materials, and Participants

All participants in our study were undergraduate students at Carleton College between the approximate ages of 18 and 22. Our sample consisted of 13 female students and 13 male students. All subjects were enrolled in the same cognitive science course, and participated in the study as one of their course requirements. The participants were asked to take part in a lexical decision task using the computer program PEBL (The Psychology Experiment Building Language), Version 0.14 by Mueller (2014). The participants ran this application on the lab desktop machines (iMac: 21.5 inch, Late 2015; running on Windows 10 Enterprise, version 1803) with standard display settings. The lexical decision task was adopted and word list modified from the original PEBL experiment battery (Mueller & Piper, 2014). Our modified word list included 167 pairs consisting of combinations of compound words, related and unrelated non-compound words, and non-words.

Our study tested 21 compound words, with 7 transparent compounds, 7 opaque-head compounds, and 7 opaque-nonhead compounds.[2] Compound words were assessed for frequency using the MCWord Orthographic Wordform Database (Medler & Binder, 2005), which scores words based on their number of occurrences per million using a database of approximately 16.8 million wordforms. The selected transparent compound frequency scores ranged from 1.4 (PANCAKE) to 36.3 (NOTEBOOK). The selected opaque-head compound frequency scores ranged from 0.05 (BOOKWORM) to 4.16 (FIREWORKS), and the selected opaque-nonhead compound frequency scores ranged from 0.6 (QUICKSAND) to 16.8 (HIGHWAY). Partially opaque compounds with low frequency scores were accepted because of the relatively low numbers of partially opaque compounds occurring in English.[3]

Each compound appeared paired with a word that was semantically related to the head of the compound, a word that was semantically related to the nonhead constituent of the compound, a word that was semantically related to the whole compound, and a word that was unrelated to the whole compound and its constituents.[4] An example of each trial type is given in order in examples (1) through (4), repeated from above.

(1) compound -- word related to compound head: NOTEBOOK -- NOVEL
(2) compound -- word related to compound non-head: NOTEBOOK -- BINDER
(3) compound -- word related to the whole compound: NOTEBOOK -- MESSAGE
(4) compound -- word not related to the compound: NOTEBOOK -- SHRIMP
(5) compound -- non-word: NOTEBOOK -- RETHLE
(6) non-word -- non-word: GRELP -- ROSCHEM

Additionally, each compound appeared with two non-words. We generated 106 original non-words to complete our wordlist. A full list of stimuli is included in Appendix A.

3.1 Procedure

All subjects completed this study in a quiet computer lab in a single session. Each trial began with a brief display of a fixation point in the middle of the screen. Then, the fixation point disappeared and a pair of letter sequences appeared. In all trials containing related or unrelated words, the compound appeared on the left. In trials containing non-words and compounds, the location of the compound varied. If subjects determined that both sequences formed English words, they pressed the left shift key on the computer keyboard. If they determined that either or both of the sequences formed non-words, they pressed the right shift key. Pressing a shift key triggered the start of the next trial. Stimuli appeared in a random order. The program interface with stimuli on screen is shown in Figure 1.

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[2] All compound words used in this experiment are usually written as one word. Although phrases that are usually written as two words, such as *air conditioner*, might potentially be considered compound words, we chose not to include them because participants might be more likely to consider them to be a phrase than a compound word.

[3] See section 5 for further discussion of potential issues with the wide range of frequency of compound words.

[4] Related non-compound words were taken from the University of South Florida Free Association Norms (Nelson, McEvoy, & Schreiber, 1998) whenever possible. We checked unrelated non-compound words against these lists to ensure that they did not have an associative connection to the compound or constituent. For a subset of compound words not included in the lists, we chose related words based on our own semantic associations with the compound.

The PEBL program tracked participants' response times and recorded participants' answers as correct or incorrect. If participants responded to a stimulus pair incorrectly, the trial was not repeated, so all participants saw all 167 stimulus pairs only once. The entire experiment took approximately 5 minutes for subjects to complete.

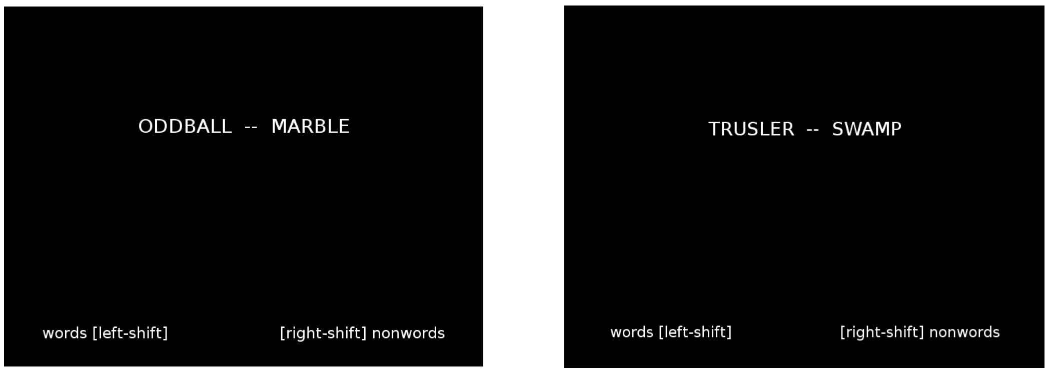

Figure 1. Program-participant interface displaying a pair of letter sequences in the middle and on-screen keyboard instructions at the bottom of the screen (Figure on the left: [left shift] "words" pairing; figure on the right: [right-shift] "nonwords" pairing). Program interface adopted from PEBL experiment battery (Mueller & Piper, 2014).

4.0 Results

Response times (RT) analysis focused on types of stimuli pairs that included compound words. The RT data for NON-WORD - NON-WORD pairs as well as NON-WORD - SIMPLE WORD pairs were not included in this analysis. Although collecting this data was necessary for running a lexical decision task, this data was irrelevant to our analysis of compound words.

In total, RT data from 26 participants were collected, and each participant's individual mean RT for each type of stimuli pair was calculated (types of stimuli pairs and abbreviations for each condition are shown in Table 1). Each participant's individual mean RT only included trials in which the participant correctly responded to the lexical decision task. The mean RTs for all participants were averaged from participants' individual average RTs. The mean RT and SD for each type of stimuli pairs are listed in Table 1. Graphs showing the interactions between mean RT in different stimuli pair conditions are displayed in Figure 2.

Comparing across different types of compound words (transparent, opaque head, opaque nonhead), in general, participants show faster mean RT when a compound is paired with a semantically related word than when paired with words related to one constituent or with unrelated words. More specifically, the participant's mean RT for the COMPOUND (including T (transparent), OT (opaque-transparent), and TO (transparent-opaque)) - W (word related the whole compound) pairing conditions are faster than that for COMPOUND - U (unrelated word) pairings. Participants also show faster RT for trials where the word paired with a partially opaque compound is related to either constituent than for COMPOUND - U trials.

Across related word types, word pairings containing a transparent compound have faster participant mean RT than both of the partially opaque compound pairings. One notable exception to this pattern is the mean RT for OT-NH, which is faster than T-NH. To consider the effects of headedness across the three types of compounds, COMPOUND - H (word related to compound head) pairings always result in faster participant RT than COMPOUND - NH (word related to compound nonhead) pairings.

Compound Type	**Paired Word**	**Stimuli Abbreviation**	**Mean RT(ms)**	**SD(ms)**
Transparent	Related to the whole compound	T-W	878	201
	Related to the compound head	T-H	904	179
	Related to the compound nonhead	T-NH	948	183
	Unrelated with the compound	T-U	932	169
	Non-word	T-NW	959	142
Opaque head	Related to the whole compound	TO-W	1020[5]	296
	Related to the compound head	TO-H	925	174
	Related to the compound nonhead	TO-NH	974	180
	Unrelated with the compound	TO-U	1007	199
	Non-word	TO-NW	975	147
Opaque nonhead	Related to the whole compound	OT-W	895	170
	Related to the compound head	OT-H	925	169
	Related to the compound nonhead	OT-NH	928	172
	Unrelated with the compound	OT-U	983	179
	Non-word	OT-NW	1031	220

Table 1: *Types of Stimuli Pairs, Abbreviations, and Mean RT and SD for each trial type*

[5] Two outliers for this trial type were well outside of the standard deviation (Mean RT = 1923 and 1826) and these data points have been excluded from further calculations. In all other circumstances, outliers have been included.

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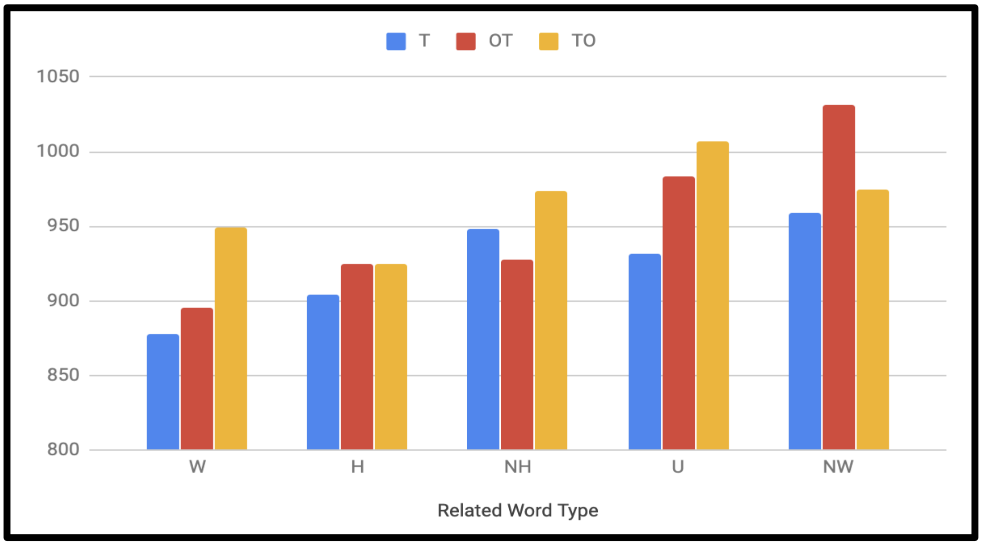

Figure 2. Average RT across participants for each stimuli pair.
The x-axis denotes the words that are paired with the compound,
and the y-axis shows RT in ms. The x-axis abbreviations are explained in Table 1.

A 3 (compound type)* 5 (related word type) two-way within-subject ANOVA was performed on the data collected comparing the participants' average RT under different stimuli pairing conditions. A significant main effect for compound type was found ($F(2,25) = 6.27$, $p = 0.01$). Additionally, a significant main effect for related word type was also found ($F(2,25) = 5.58$, $p < 0.01$). The interaction of the main effects were significant ($F(3, 25) = 2.73$, $p = 0.03$). The effect of the type of compound is significantly influenced by which type of related word is paired with the compound.

5.0 General Discussions

Our results largely echo those in previous studies that found that participants response times were faster when target words appeared with semantically associated words. As in Meyer and Schvaneveldt's (1971) experiment, RTs for partially opaque stimuli that paired a compound word with a related word are faster than those that included an unrelated word. However, trials where transparent compounds appeared with a word related to their nonhead constituent were processed more slowly than those paired with unrelated words. This result was inconsistent with previous research (e.g. Sandra 1990).

Our first hypothesis predicted that faster RTs would also be recorded for pairs where the non-compound word was related to only one of the constituents than for pairs with unrelated words, and this was supported by our results, with the aforementioned exception. We also predicted that transparent compound words would have faster RTs than partially opaque compound words, showing a greater effect from related words than seen in partially opaque compounds. This was generally supported by our results, with faster RTs for transparent compound words paired with a whole-related, head-related, and unrelated word than the RTs of partially opaque compound words paired with each of those types of words. However, results for trials where the paired word was related to the nonhead constituent failed to support this hypothesis, with faster RTs seen for partially opaque compound words than for transparent words. Finally, our hypothesis that RTs would be faster when paired words related to the compound word's head constituent, as opposed to its nonhead, was consistently supported.

The findings of the current experiment offer some support to trends found in previous research that show processing of compound words by constituent. Our results also suggest that transparency and headedness influence compound word processing in different ways. When the head constituent was semantically primed, RTs were consistently faster than when the nonhead was primed. This was not the case for transparency: priming a transparent head constituent resulted in faster RTs than priming an opaque head component, but RTs were faster when an opaque nonhead constituent was primed than when a transparent nonhead constituent was primed. This suggests that increased activation of a compound word's head might decrease RTs more consistently than activation of a transparent constituent. Currently we are unable to explain why headedness might have a more consistent influence than transparency, or why our transparency findings are inconsistent with previous research.

5.1 Limitations and Further Research

The current study had a number of limitations. Further research on this topic should consider limiting the number of experimental conditions (i.e. stimuli pairings), and that might provide a more detailed picture of how headedness and transparency of compounds would affect the extent to which certain constituents are more semantically primed than others. It would also be beneficial to isolate these variables (transparency and headedness) when designing future experiments in order to pinpoint how the two components would separately affect activation of semantically related words. In addition to transparency and headedness, it has been suggested that other factors can influence activation of compound constituents as well. For example, Jarema et al. (1999) briefly suggested that semantic priming may differ in strength based on the position of the constituent within the word, whether or not the constituent is the head of the compound. For example, the first morpheme might always be more strongly activated than the second morpheme, even if the second morpheme is the head. Another potentially influential factor is frequency of compound words and their semantic associates. Our study used words with a relatively wide range of frequency, and we did not compare results for high-frequency and low-frequency words within this study. Controlling more strictly for frequency in future studies could possibly yield different results.

Our study was additionally limited by the relatively homogenous participant group. Since participants were recruited from a college level cognitive psychology class, all participants have prior knowledge and practice with lexical decision tasks. The RT data we gathered could be affected by the participants' relative expertise in the experimental procedure. Additionally, our version of lexical decision task computer program, adopted and modified from the original PEBL experiment battery (Mueller & Piper, 2014), did not repeat trials in which participants answered incorrectly. As a result of this, we excluded RT data for incorrect responses, but if these trials had been repeated instead, we could have analyzed data for all stimuli for all participants.

6.0 Conclusion

Altogether, the results of our study can be considered tentative additional support for previous research that has indicated that constituents of compound words may be activated individually during processing, and that this activation is increased by higher levels of transparency and headedness. This suggests that at least some compound words are represented in our mental lexicon by morphemes, using two entries, one for each constituent of the word.

This current study still leaves some unanswered questions for further research to investigate. Future studies could help determine whether there is a significant effect on RT for both constituent transparency and headedness in compounds, and could reveal more conclusive information about the interaction of those two factors. Additionally, our study did not investigate how semantic priming of separate constituents would affect RT for compound words that are completely opaque (e.g. *hogwash*). Future research could also be done using alternative methodologies, such as single word semantic priming techniques, where the prime and the target appear in sequence, not at the same time. Understanding more about how headedness and transparency, including low levels of transparency, affect activation of constituents in compound words has the potential to reveal more information about how more types of compound words are mentally represented and how the lexicon is organized overall.

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Appendix A
List of Stimuli Pairs Used in the Lexical Decision Task

		Related Type			
Word Type	**Compound**	**W**	**H**	**NH**	**U**
T	NOTEBOOK	BINDER	NOVEL	MESSAGE	SHRIMP
	BATHROOM	STALL	LOUNGE	TOWEL	SEASON
	DOORWAY	ENTRANCE	TRAIL	HINGE	ELEMENTS
	LIPSTICK	COSMETICS	TWIG	MUSTACHE	BEAR
	TEAPOT	PLATE	STEW	CAFFEINE	CHARITY
	OATMEAL	CEREAL	DINNER	GRAIN	TRUTH
	PANCAKE	SYRUP	FROSTING	SPATULA	SPIDER
TO	DOUGHNUT	PASTRY	ACORN	MONEY	CABINET
	SKYSCRAPER	TOWER	CAR	COMET	BAMBOO
	ODDBALL	WEIRDO	MARBLE	NUMBERS	ALMOND
	HEATWAVE	HUMIDITY	OCEAN	CALORIE	VANILLA
	HONEYCOMB	BEEHIVE	BRUSH	SWEETHEART	THEATER
	FIREWORKS	MATCHES	LABOR	CHIMNEY	AUTUMN
	BOOKWORM	LIBRARIAN	BAIT	STORY	MISTAKE
OT	BUTTERFLY	MOTH	PLANE	BREAD	SHELF
	HIGHWAY	BILLBOARD	DOOR	PEAK	CONTAINER
	SOFTWARE	COMPUTER	HOUSE	PILLOW	MUSTARD
	GREENHOUSE	GARDEN	PORCH	ALGAE	BUBBLE
	FLASHLIGHT	BATTERY	LASER	NEWS	RAVEN
	BEDROCK	SOIL	MUSIC	SHEETS	JELLY
	QUICKSAND	SWAMP	BEACH	BUNNY	CHIPS

Non-words used included: GRELP, ROSCHEM, FONGRE, ABSIVA, DELINSE, PANCE, KELNE, ZIDZUK, BETHEW, HUDNUM, MEWORN, PROUVOS, FENOIN, MORRICK, DOBGIR, WOLDER, TRIGH, NULWEN, ANOUP, HOLGIN, FALOD, NORSFEL, LENGAT, JERIVE, FLERF, SCHUNDLE, TRETIVI, CLOPY, PABRICK, MOKEN, SORGED, CARHEK, VALCOW, ERIFEN, DROWK, SIDSUSS, REDULM, WOUSH, MADRIME, LOKER, LENCHUN, WHOLMS, ANGRET, DILENGE, FLOTIEP, WASVER, INERVEL, DURGIL, BLOPEY, CARDOI, MINOBI, BUSHIE, SARIFE, WHOISH, FLARD, TRUSLER, SHAIRIFE, QUASHEV, FORGRUE, COCUTI, DACHBLEE, COMMEI, NEUFF, TOOVY, RETHLE, RORKLE, NIMMUL, TRECHER, HUAKIE, OBLAN, YOSSER, SUNGTH, NUPEY, CROMP, CHRALL, ELLIMB, GROME, JUNBY, JIBBLE, KISHWEL, IGNIBUS, PLOVISH, HOPNEEL, PHESTRA, LULLOW, SHAVIL, NOURD, PRIEL, CRUNFY, CHERRA, FRUKE, SLOUL, CLORK, BONEFO, SIVIAL, HEXIMIL, QUAGLE, STOILER, PLOISH, WALBLE, TRILIA, YENLEY, BURIK, MURFUS, PRINUS, WORVEX.

Some non-words appeared with compound words, some with non-compound (simple) words, and some only with other non-words. See section 3.2 for further explanation of stimulus creation.