Stimulus-Dependent Processing Strategies in the Cognitive System: Evidence from Lexical Decision of True- And Non-Words

[1]Shivani Tiwari, [2]Gopee Krishnan & [3]Rajashekar Bellur

Abstract

The cognitive models of word processing have gained considerable attention in the recent past. Such models have been successful in explaining a large number of observations in both normal and disordered word processing. Whether the cognitive system employs a serial or parallel processing has been overwhelmingly debated in the field cognitive linguistics. In this context, the present study attempted to investigate the processing capabilities for true words as well as the legal and illegal non-words, using a lexical decision task in a group of normal subjects. The results revealed that the true words were processed faster compared to non-words. In addition, the comparison of lexical decision time for legal and illegal non-words revealed a statistically significant difference between the two sets. We argue that the parallel processing strategy facilitates faster processing and it is employed in the processing of true words while serial processing is employed in legal and illegal non-words. This may be considered as an evidence for the stimulus-dependent processing strategies employed by the cognitive system while processing written stimuli.

Key words: Serial and Parallel processing, Legal and illegal non-words, Written word processing, Lexical decision, Stimulus-dependent strategies

The recent models of language processing have made significant contributions to our understanding on the underlying processes in many complex cognitive tasks such as naming, reading, writing etc. One of the most influential models of single word processing is postulated by Patterson and Shewell in 1987. This model has been successful in explaining most of the normal as well as disordered linguistic processing not only in the primary linguistic tasks such as speaking and understanding but also in the secondary linguistic domains such as reading and writing.

The ability to read letter strings requires the translation of visual codes (orthography) into pronunciations (phonology), with meaning (semantics) emerging when the pronunciation corresponds to a known word. During the course of learning to read, knowledge of the sound associated with sub-word letter units is established, which enables the pronunciation of new words that the reader has never encountered. In the experimental settings, these novel words-like strings are referred to as pseudowords (Price & Michelli, 2005).

Lexical decision paradigm

One of the most commonly employed paradigms in the psycholinguistic research is the lexical decision task (LDT). In this task, the subjects are required to make a quick decision whether the given string of letters constitute a true word or a non-word (Wagenmakers, Zeelenberg, Steyvers, Shiffrin, & Raaijmakers, 2004). While performing this task, the subject first extracts the visual features of the letters as well as the relative position of the letters in the letter strings (Dijksrta, 2007). This is essentially a stage of visual word recognition. Once the visual features have been recognized, the subject then makes an 'Orthographic Input Lexicon' (OIL) – an abstract representation of the visual word image. Following this stage, the subject matches the activated unit from OIL with the semantic system to find the best match. The lexical decision is said to have taken place as soon as the subject finds a corresponding entry in the semantic system that matches with the activated OIL (Southwood & Chatterjee, 2000).

Although lexical processing appears smooth with the above explanation, there are certain conditions where the entire word processing system can be taxed by the stimulus quality. For instance, when the letter string does not constitute a familiar word (e.g. *kitthougue* – meaning sinistral) – be it a true- or non-word – the subject

[1]Lecturer, Department of Speech and Hearing, Manipal College of Allied Health Sciences, Manipal University, Karnataka, [2]Asst. Professor, Department of Speech and Hearing, Manipal College of Allied Health Sciences, Manipal University, Karnataka, email:brain.language.krishnan@gmail.com., [3]Professor and Dean, Department of Speech and Hearing, Manipal College of Allied Health Sciences, Manipal University, Karnataka.

fails to form an OIL representation. In this context, the subject is forced to select a sublexical (phonological) route, where s/he converts each grapheme into its corresponding phoneme and then combines them to read the word. Evidently, since the letter string being either an unfamiliar true word or a non-word, there is no corresponding activation at the semantic/conceptual level. This simplifies the lexical decision task as the subject does not have to search the corresponding entries in the mental lexicon. However, there are some caveats to this arguably simple explanation.

The word processing becomes quite laborious in the case of letter strings that form a 'pronounceable' word – be it a (unfamiliar) true word or a non-word. The non-words, as a class, could be of two different types: *legal* and *illegal*. The legal non-words are those words that appear like true words. That is, they follow the phonotactic principles of the given language, and therefore, are pronounceable like true words (e.g., in English, *Lenit*). The illegal non-words, on the other hand, do not follow the phonotactic rules, and therefore, are non-pronounceable (e.g., in English, *Lomkn*). The processing of these two types of non-words is different from that of the true words, as they do not have the corresponding semantic representations in the mental lexicon. In addition, the processing of legal and illegal non-words could be different from each other. In the case of legal non-words, the subjects generate the OIL due to their lexical resemblance (i.e., word-like appearance). However, the illegal non-words do not generate the OIL due to their non-lexical nature (Kinoshita & Lupker, 2007).

The above-mentioned assumptions can be explained using one of the widely-acknowledged word processing models proposed by Patterson and Shewell (1987).

As indicated in Figure 1, a true word (e.g., *Latin*) is primarily processed through the semantic route A. In a LDT, the subject makes a *YES* response after the corresponding entry in the lexicon has been activated by the word string *Latin*. However, in addition to the initial feature extraction, this requires two stages of processing: an initial formation of the OIL followed by a semantic search. These two processes are performed at the expense of increased reaction time. In the case of a legal non-word (*Lenit*), pathway B is presumed to be activated, as the legal non-words do not have their corresponding entries in the semantics. Yet, owing to their lexical resemblance, an OIL is generated. In this context, it is possible to assume that the reaction time (RT) for LDT would be highest for legal non-words. The reasons for this assumption are that (a) the letter string appears lexical, and therefore generate an OIL, and (b) this forces the subject to search the entire semantic system before an accurate *NO* response is made. Such an extended semantic search would invariably increase the LDT for legal non-words. In contrast to this, the illegal non-words (*Lomkn*) fail to generate an OIL owing to their poor lexical semblance. In this context, we can expect the shortest RT for LDT in the case illegal non-words as the subject is able to make a faster response even without the formation of OIL and the subsequent semantic search.

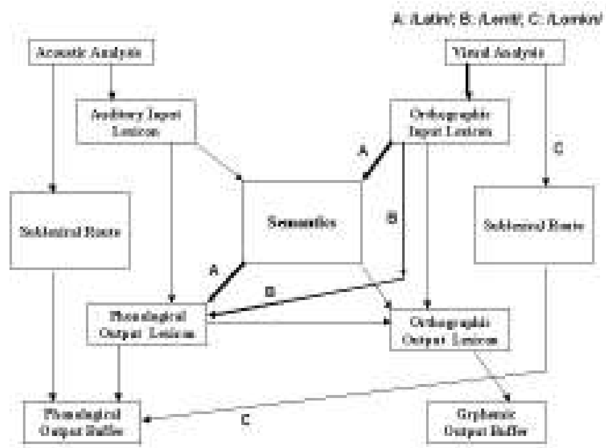

Figure 1: Schematic representation of the processing pathways of three different types of written stimuli using Patterson and Shewell's (1987) word processing model.

Serial vs. parallel processing in the cognitive system

Whether the cognitive system employs a serial or parallel processing strategy is a matter or extensive debate in the field of cognitive linguistics. The proponents of serial processing models (e.g., Coltheart & Rastle, 1994; Rastle & Coltheart, 1999; Kwantes & Mewhort, 1999) assume that the bottom-up processing in word processing is strictly serial in nature. That is, recognizing as well as deciding the lexical nature of a letter string is assumed to be in the following strict serial order: initial coding of the letter features, recognizing the letters and their relative positions in the letter string, identifying a visual word (orthographic input lexicon), semantic activation etc. In contrast to the serial processing, the proponents of parallel processing models a (e.g., McClelland & Rumelhart, 1981; Howard,

1991) assume that the processing spreads parallelly to multiple levels, simultaneously. That is, for example, extracting the letter features of a given letter in a string would simultaneously activate its corresponding entries at the letter, word, and the conceptual levels. This facilitates a quicker processing of the stimulus items in a task like lexical decision. With this brief description of the processing strategies in written word processing, we proceed to the aim of the current study.

Aim of the study

The present study aimed at investigating into the nature of lexical processing of three different groups of written stimuli (letter strings) viz. the true words, legal non-words, and illegal non-words using a lexical decision paradigm.

Assumptions of the study

We argue that if the RT for lexical decision task (RT_{LDT}) were highest for legal non-words and shortest for illegal non-words with the true words between these two, it may be considered as a strong evidence for the serial processing in the cognitive system. If any divergence from this distribution of LDT RTs is noticed, it may be considered as strong evidence against the serial processing strategy, perhaps supporting the parallel processing strategy.

Working hypothesis

Specifically, in account of the serial stage processing, we hypothesized that:

The legal non-word LDT_{RT} *> true word* LDT_{RT} *> illegal non-words* LDT_{RT}

Method

Participants

Twenty students of Manipal University (10 males & 10 females; Mean age = 20 years, SD = 2) were selected for the current study. The subjects were fluent English speakers with the medium of instruction being English from the LKG level, although their native language was not English. None had any history of neurological/psychiatric illness in the past. All subjects were right-handed and had normal or corrected-to-normal vision.

Stimuli

The stimuli consisted of 30 items (see Appendix) in three categories: true words (e.g. *Latin*), legal non-words (e.g. *Lenit*), and illegal non-words (e.g. *Lomkn*). Each category had 10 items each. The stimuli were balanced for the visual complexity by keeping the number of graphemes constant across them. All stimuli were rated by a group of five normal subjects on their lexical attribute (true vs. non-word; legal vs. illegal non-word).

Procedure

The participants were made to sit comfortably in a quiet room. They were instructed to look at the letter series displayed on the computer monitor. They were asked to press the '*m*' button of the keyboard as soon as they saw the displayed letter series represented a true word. If the letter series did not make a true word, '*n*' button press was required. Instructions were provided to rest their middle and index fingers on buttons '*m*' and '*n*', respectively, in order to avoid the time lag while reaching the fingers to the buttons during each trial. Following these instructions, they were given three trial items before the commencement of the actual test items. The stimuli were presented through DMDX reaction time software (Forster & Forster, 2003). In each trial, a '+' appeared on the center of the computer screen for 500 ms. It was followed by a blank screen for 500 ms. At the end of this period, the stimulus was presented. Each stimulus lasted on the computer monitor for 2000 ms. The reaction time clock was set synchronous with the appearance of the letter strings on the screen. All the stimuli were randomized and the subject completed the experiment in a single session without any break. The entire data collection for a single subject lasted less than 10 minutes. Using SPSS (version 16) software for Windows, the reaction time and error data were subjected to separate One-way ANOVA to find out the difference in processing across the three types of stimuli.

Results

Reaction time

To analyze the reaction time difference among the three stimulus conditions, only accurate responses were considered. The descriptive statistics (Mean and Standard Deviation) for the true, legal and illegal non-words are given Table 1. The mean LDT for the true words (e.g., *Latin*) was shortest compared to the illegal non-words (e.g., *Lomkn*), which in turn was shorter than that of the legal non-words (e.g., *Lenit*).

Stimulus type	Mean (SD) Reaction Time (ms)
True words	639.15 (123.32)
Illegal non-words	704.12 (149.38)
Legal non-words	821.72 (180.93)

Table 1: Mean and SD of various stimulus types for a group of 20 subjects

The results of One-way ANOVA revealed a significant effect (F (2, 57) = 7.314, p < 0.001) across the LDT of the three stimulus types. The post-hoc (LSD) analysis showed a significant difference in LDT between the legal non-words and true words, whereas legal versus illegal non-words and illegal non-words versus true words did not show a significant difference in LDT (See Table 2).

Stimulus type	Mean RT difference	Confidence interval at 95%		Significance
		Lower	Upper	
Legal vs. Illegal Non-words	117.6	-1.77	236.97	0.055
Legal Non-words vs. True words	182.57	63.20	301.95	0.001*
Illegal Non-words vs. True words	64.97	- 54.39	184.35	0.054

*Significant at 0.001 level

Table 2: Pair-wise (post-hoc) comparison of reaction times across the three stimulus types.

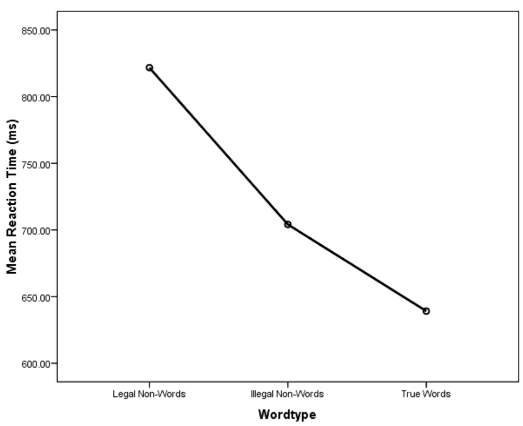

Figure 2: The mean reaction times as a function of the stimulus types

Error analysis

The mean (and SD) of the errors (Table 3) across the subjects in the three experimental conditions were obtained. The error means were subjected to One-way ANOVA, using SPSS 16 for Windows.

The results of One-way ANOVA of the error means reveled a significant effect (F (2, 57) = 12.938, p < 0.001) across the errors in three stimulus types. The post-hoc (LSD) analysis showed that the errors in the legal non-words were significantly different from both the true words as well as the illegal nonwords. However, the difference in mean error rate was not significant between the true words and the illegal non-words.

Stimulus type	Mean (SD) Errors
True words	0.45 (0.51)
Illegal non-words	0.25 (0.44)
Legal non-words	1.75 (1.61)

Table 3: Mean and SD of various stimulus types for a group of 20 subjects

Stimulus type	Mean error difference	Confidence interval at 95%		Significance
		Lower	Upper	
Legal vs. Illegal Non-words	1.5	0.85	2.14	< 0.001
Legal Non-words vs. True words	1.3	0.65	1.94	< 0.001*
True words vs. Illegal non-words	0.2	-0.44	0.84	0.535

*Significant at 0.001 level

Table 4: Pair-wise (post-hoc) comparison of reaction times across the three stimulus types.

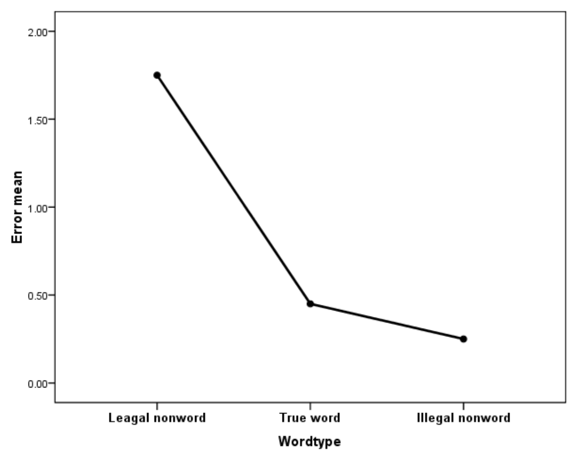

Figure 3: The mean error rates as a function of stimulus types

Discussion

The experiment reported in the current study aimed at investigating into the nature of lexical processing in three groups of written stimuli: the true words, legal non-words, and illegal non-words, using a lexical decision task. A group of 20 subjects participated in the study.

Reaction time

Considering the LDT of the three groups of stimuli, as seen in Figure 2, the legal non-words (e.g., *Lenit*) required the maximum time compared to illegal non-words (e.g., *Lomkn*) and true words (e.g., *Latin*). However, the RT of the legal non-words showed significant difference only with that of the true words, not with illegal non-words. The possible mechanism for this increased RT in the case of legal non-words may be attributed to the combination of non-semantic and legally plausible (lexical) nature of such stimuli. For the participants to make a lexical decision of a legal non-word stimulus, an exhaustive search of the lexicon is required. That is, only after a complete search of the mental lexicon, a lexical decision (of *NO*) can be made for legal non-lexical words (Murray & Forster, 2004). This process is performed definitely at the cost of increased reaction time. In addition to this, the legally plausible nature of the stimuli would further delay the search, due to their resemblance to true words. In this context, the subjects were forced to search entire lexicon to find out the conceptual representation of these word-like letter strings, at the cost of extended reaction time. Thus, this finding supports our assumption that the legal non-words would exhibit highest RTs.

In the case of lexical decision for illegal non-words (e.g., *Lomkn*), the aforementioned mechanism may not hold true. That is, before an accurate judgment (of *NO*) is made, the subjects should search the entire lexicon, requiring higher RT for lexical decision. However, the legally implausible nature of these stimuli is expected to terminate the search at an early stage (at the level of OIL) as the letter string does not constitute a pronounceable word, thereby preventing the necessity for the subsequent semantic search. In our experiment, the illegal non-words exhibited shorter reaction times compared to the legal non-words, approving such kind of facilitation in the lexical processing.

In clear contrast to our hypothesis based on the serial stage processing, the absolute reaction time of the true words (e.g., *Latin*) were shortest among the three stimulus conditions. Theoretically, we expected a middle stage for true words as they essentially involve the activation of corresponding entries at the OIL and the subsequent search in the mental lexicon at the cost of increased RT. Employing the serial model of lexical processing, this finding is difficult to explain. It was assumed that the true words would require longer time compared to the illegal non-words. The reason for such an assumption was that the true words have a semantic representation in the mental lexicon as well as they are legally plausible words. The presence of a semantic representation in the mental lexicon would invariantly require the search and subsequent conceptual activation before a lexical decision is made. This search process is invariably at the cost of reaction time. However, in the case of illegal non-words, the implausible nature of the stimulus (unlike in legal non-words) was assumed to prevent the lexical search for their corresponding semantic representation even before it is commenced. That is, the word processing was expected to be terminated at an early state, as the letter strings did not constitute plausible words. However, such an assumption was proved wrong from the current results. Though the difference was statistically not significant, the illegal non-words required more time for the lexical decision irrespective of their lexically implausible nature compared to the true words.

The results of the present study were, thus only in partial agreement with the hypothesis we generated. That is, congruent with our predictions, the legal non-words showed highest RT relative to the other two stimulus conditions. However, with respect to the illegal non-words and true words the obtained results disproved our prediction. That is, unlike we assumed, the true words showed shortest reaction times compared to the illegal non-words. This observation is quite incongruent with the tenets of serial stage processing (as the processing of true words involve activation at OIL and subsequent semantic search unlike illegal non-words, invariantly at the cost of RT). Irrespective of such processing demands, the facilitation of the true words may be taken as an evidence for the parallel processing in the cognitive system. In parallel processing systems, the information flows to nodes at multiple levels, i.e., to the lexical, semantic, phonological etc. (e.g., McClelland & Rumelhart, 1981; Howard, 1991). Therefore, it may be considered that while processing the true words, cognitive system calls for a parallel processing strategy whereas in the case of non-words, a serial processing strategy may be employed. This may be considered as an evidence for the stimulus-dependent strategy employed by the cognitive system.

Error analysis

The mean error rates in the three experimental conditions revealed some interesting findings. As Figure 3 indicates, the highest error rate was observed in the legal non-words, paralleling their reaction time finding. However, the true words, unlike their reaction time data, showed more errors than the illegal non-words, although the difference in error rates between the true and illegal non-words were not statistically significant (result here). Therefore, the reason for the reduced error rate in illegal non-words may be attributed to the absence of OIL formation in these words. That is, the lexically implausible nature of illegal non-words helps the subjects to make more accurate decision, although they required slightly more processing time than the true words, as evidenced by the RT data. It may, therefore be possible to infer that in the case of true and illegal non-words, there existed a *speed-accuracy trade-off*. That is, true words were faster in processing with slightly elevated error rates, whereas the illegal words were more accurate in processing with slightly elevated processing time compared to true words. Interestingly, such a speed-accuracy trade-off was not observed in the case of legal non-words, perhaps owing to their non-semantic as well as lexically plausible natures.

One possible criticism for the explanation of the facilitation of the true words compared to non-words (both legal as well as illegal) may be the frequency effect (Oldfield & Wingfield, 1965; Shatzman & Schiller, 2004). That is, it is arguable that subjects perform faster in the case of true words since such words are more familiar than non-words. Although, such a criticism may be difficult to reject on the grounds of the comparison between words and non-words, it simply fails to explain the RT difference between legal and illegal non-words. That is, without regard to the pronounceable nature of legal words compared to illegal ones, it is apparent that neither of these occurs in the day-to-day life. Hence, we argue that the familiarity effect alone fails to explain the observed findings in the current study. Finally, we caution that such a facilitation of true words through the parallel processing may be seen only in skilled readers, as children, in their period of mastering the reading skills, often rely on the sublexical or phonological route (Frith, 1985). Hence, it may be interesting to study how such developing children perform the same task used in the current study.

Conclusions

The present study, using lexical decision task in a group of normal subjects, provides empirical evidences for the stimulus dependent allocation of the processing strategies in the cognitive system. In the case of true words, the system employed a parallel processing strategy which was quicker than the serial processing employed in the case of non-meaningful stimuli.

References

Coltheart, M., & Rastle, K. (1994). Serial processing in reading aloud: Evidence for dual-route models of reading. *Journal of Experimental Psychology: Human Perception and Performance, 20*(6), 1197-1211.

Dijkstra, A. (2007). Task and context effects in bilingual processing. In I. Kecskes & L. Albertazzi (Eds.), *Cognitive aspects of bilingualism*. Dordrecht: Springer.

Frith, U. (1985). Beneath the surface of developmental dyslexia. In K. E. Patterson, J. C. Marshall & M. Coltheart (Eds.), *Surface Dyslexia: Neuropsychological and Cognitive Studies of Phonological Reading*. London: Lawrence Erlbaum.

Forster, K. I., & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. Behavior Research Methods, Instruments, & Computers 35, 116–124.

Howard, D. (1991). Letter-by-letter readers: Evidence for parallel processing. In D. Besner & D. W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 34-76). Hillsdale, NJ: Lawrence Erlbaum Associates.

Kinoshita, S., & Lupker, S. J. (2007). Switch costs when reading aloud words and nonwords: Evidence for shifting route emphasis. *Psychonomic Bulletin & Review, 14*(3), 449-454.

Kwantes, P. J., & Mewhort, D. J. K. (1999). Evidence for sequential processing in visual word recognition. *Journal of Experimental Psychology: Human Learning and Memory, 25*(2), 376-381.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effect in letter perception: Part 1. An account of basic findings. *Psychological Review, 88*(5), 375-407.

Murray, W. S., & Forster, K. I. (2004). Serial Mechanisms in Lexical Access: The Rank Hypothesis. Psychological Review, 111(3), 721-756.

Oldfield, R. C., & Wingfield, A. (1965). Response latencies in naming objects. *Quarterly Journal of Experimental Psychology, 17*, 273-281.

Patterson, K. E., & Shewell, C. (1987). Speak and spell: dissociations and word-class effects. In M. Coltheart, R. Job & G. Sartori (Eds.), *The cognitive neuropsychology of language*. Hillsdale, NJ: Lawrence Erlbaum.

Price, C. J., & Mechelli, A. (2005). Reading and reading disturbances. *Current Opinion in Neurobiology, 15,* 231-238.

Rastle, K., & Coltheart, M. (1999). Serial and strategic effects in reading aloud. *Journal of Experimental Psychology: Human Perception and Performance, 25*(2), 482-503.

Shatzman, K. B., & Schiller, N. O. (2004). The word frequency effect in picture naming: Contrasitng two hypotheses using homonym pictures. *Brain and Language, 90*, 160-169.

Southwood, M. H., & Chatterjee, A. (2000). The interaction of multiple routes to oral reading: Evidence from Dissociations in Naming and Oral Reading in Phonological Dyslexia. *Brain and Language, 72*, 14-32.

Wagenmakers, E. J. M., Zeelenberg, R., Steyvers, M., Shiffrin, R., & Raaijmakers, J. G. W. (2004). Nonword repetition in lexical decision: Support for two opposing hypothesis. *The Quarterly Journal of Experimental Psychology, 57 A (7)*, 1191-1210.

Acknowledgments

The authors thank the participants for their cooperation.

Appendix – Stimuli

True Words	Legal non-words	Illegal non-words
Latin	Lenit	Lomkn
Pants	Pomak	Pxuvt
Break	Bitan	Bxopl
Cycle	Cemos	Cwbuk
Radio	Rolen	Ryltk
Diary	Dopan	Mwxip
Ivory	Insok	Daqtr
Mouse	Mesat	Mkstu
Keep	Kropt	Kvlir
Queen	Quamp	Qgcoh