Finding Harmony in Chaos: The Dynamics of Bilingual Lexical Processing

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19.06.2015
Word Count: 15,165 (only body paragraph counted)
Abstract

The study was aimed at investigating whether bilingual lexical processing can be seen as an interaction-dominant system. In particular, four hypotheses were formulated to address the question, including the issues of variability in L1 and L2 performance within bilinguals, stability of lexical representation, effect of very immediate language use, and presence of fractal self-organizing patterns as manifested in pink noise in trial-by-trial fluctuation. To verify the hypotheses, both linear and non-linear approaches to reaction time data gathered from a series of lexical decision experiments with context manipulation conditions, which involved four advanced Indonesian learners of English were applied. The data analyses confirmed that L1 performance was consistently faster than L2. Next, lexical items were found to be flexible, which means that they are context sensitive and exhibits patterns of dynamic self organization over time. A more stable representation found in L1. Furthermore, very immediate language use was found to have an effect on L2 lexical processing, whereas the same pattern was not found in L1. Finally, both power spectral density estimation (PSDE) and standardized dispersion analysis (SDA) confirmed that the fractal dimension of the trial series data indicated the presence of pink noise, with more pronounced pattern found when L2 lexical decision tasks performed after using the same language. Finally, this study verified the notion that lexical processing in bilinguals can be considered as an interaction-dominant process, whereby human cognition does not work following a modular structure as described by the computer metaphor. Instead, in line with Spivey & Dale (2004) who proposed that human cognition is always on continuous flow, it can be proposed that lexical processing is analogous to a flowing river, which is dependent on time and context.

Keywords: pink noise, bilingual lexical processing, lexical representation
Acknowledgments

Pink noise can be loosely defined as a continuous journey to seek a delicate balance between order and chaos. Apparently, not only does pink noise become the main focus of the study, but it also perfectly describes my overall academic adventure in RUG for the last one year, especially during the writing of this thesis. Specifically, the greatest revelation that I learned from the process is that, just as pink noise emerges in tedious trial-by-trial process, perseverance is indispensable to finish the task; and it is only by His daily sufficient grace, which I personally experience through the help, support and encouragement along the way that I can get to the finish line. Therefore, I would like to express my sincerest gratitude to all individuals who contributed to the completion of this thesis.

I am deeply indebted to Prof. Kees de Bot for his patience and guidance. It is such a blessing to work under his supervision as his insightful suggestions have always succeeded to encourage a village school teacher like me to work on a research paper. My gratitude also goes to Dr. Wander Lowie, my second supervisor, especially for the tremendous help with the statistics. Next, I would also like to thank the four participants of the study whose name I cannot reveal due to the ethical reasons. I cannot thank you enough for your willingness to take part in the tiring experiments. My genuine appreciation also goes to the two anonymous reviewers for the useful comments. I would also like to extend my sincere gratitude to Nuffic Neso Indonesia for giving the life-changing opportunity to pursue a higher education in the Netherlands. I also owe a debt of gratitude for the never ending moral support to my family and friends: my mother Monika Rini, my father Wahyudhi, my two little sisters Intan and Nia, my best friend Yanti. Thank you for believing that I can finish what I have started, even at times when I doubt myself. My genuine gratitude also goes to Simone Freije, Fang, and Triyani for the friendship as I am away from home. Finally, this thesis is dedicated for my beloved fiancé, who always dreamed of pursuing a higher education abroad. I believe that he would look down from Heaven and smile, knowing that his dream has been realized.
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CHAPTER 1
INTRODUCTION

To date, the complexity surrounding the issue of multilingual minds has sparked bilingual lexical processing research. Of particular concern is the question on how different lexical items from different languages are stored, accessed and selected within a bilingual mind. Regarding this question, various proposals have been made to solve the puzzle of how bilingual lexicons are organized; however, no conclusive agreement has been reached yet. For example, research into the bilingual lexicon has not yielded one solid answer to the question of whether there is only one integrated lexicon for the two languages (c.f. Francis, 1999), or whether there are two separate lexicons for each language (c.f. Dong, Gui, & Macwhinney, 2005). Despite the various conclusions, traditional research on lexical processing commonly shares the same componential dominant approach. This approach, as represented by computer metaphor (Lowie, Plat, & de Bot, 2014; Spivey & Dale, 2004; Van Gelder & Port, 1995), has attempted to resolve the question by relating the process to structural and hierarchical models (e.g. de Bot, 1992; Dijkstra & Van Heuven, 1998). The simplicity of the componential dominant approach has made it possible to break down the complex nature of language processing into smaller components. Hence, it is assumed that the answers concerning the overall system can be resolved through combining and summing up the solution at the componential levels. In addition, since the component-dominant approach assumes that
human cognition operates in a similar way as a computer algorithm, lexical processing as a part of cognitive function is expected to work in modular and sequential ways, whereby lexical items are independent of each other’s and were presumed to behave in passive manners (c.f. Jackendoff, 2002). The advantages of the componential-dominant approach are mainly based in clear and simple structures that make it easier to arrive at an initial understanding of bilingual language processing. However, critics have been leveled to the approach for being too reductionist, and against the cognitive ecology whereby process flows in a continuous fashion and each stimulus is dependent and inseparable from all other stimuli (Spivey & Dale, 2004; Waegenmaekers, Lowie, Schoonen, Plat, & de Bot, 2014).

Assuming that the human mind is dynamic and continuous, Spivey & Dale, (2004) challenged the notion of discrete representational states within componential-dominant approach by suggesting a more interactive dominant approach. In particular, this approach argues that the foundation of the continuity lies in the surrounding environment, and that the flow of stimulus activation should not be viewed as segmented, but rather as an intact entity. Consequently, the component-dominant models of the bilingual lexicon do not fit in this interaction-dominant approach. Perhaps, a link between the interactive-dominant approach and bilingual lexicon models can be found in Elman's (2011) revolutionary proposal that lexical representations are not necessarily stored within a lexicon, but that they are dynamically represented within the context. Furthermore, the interactive-dominant notion of continuous dynamic changes in a time-space domain can also be explained by Dynamic System Theory (DST) that views language as “dynamic,
complex, nonlinear, unpredictable, sensitive to initial conditions, sometimes chaotic, open, self-organizing, feedback sensitive, adaptive, and [...] fractal in shape (Larsen-Freeman, 2007, pp. 35)”. Hence, it can be concluded that the common ground for the interaction-dominant approach and DST is in the view that language processing happens in a constant dynamic coordination between components within time and space contexts.

Contrary to the traditional component-dominant approach, the interaction-dominant approach promises a more ecological procedure to get a holistic insight into bilingual lexical processing (Spivey & Dale, 2004). As the main property of the approach lies on the intact continuous flow of the mind, an investigation into bilingual lexicon requires data on online performance in intact order. Provided the original orders of a trial-by-trial data series are preserved, variability patterns that emerge over time can be revealed. Such data can be obtained through reaction time experiments widely used in cognitive psychology experiments. Unlike the traditional approach that disregards the order of the data, and focuses on central tendency to examine items individually independent of others, the interaction-dominant approach takes a non-linear view on the order of the data and considers variability residing in the trial-by-trial fluctuation as an informative resource to arrive at the understanding on bilingual lexical processing (Lowie et al., 2014; Van Orden, Kloos, & Wallot, 2009; Waegenmaekers et al., 2014). Particularly interesting is the emergence of a signal with 1/f scaling relation, i.e. the frequency spectrum is inversely proportional to the frequency of the signal, or commonly referred to as pink noise due to the pink appearance of visible light with this power spectrum (Kello, Anderson, Holden, & Van Orden, 2008). The presence of pink noise has been presented
as evidence of self-organized criticality which signals the emergence of complexity (Bak, Tang, & Wiesenfeld, 1987), and optimal coordination between mind, body and environment (Van Orden et al., 2009). Pink noise spectral density, which is located between completely random behaviors referred as “white noise” and overregulated behavior associated with “brown noise”, signifies optimal balance of coordination within a system (Holden, 2005). Interestingly, pink noise is ubiquitous in all dynamic systems, and indicates the well-being in the form of metastable coordination of the systems (Kello et al., 2008; Szendro, Vincze, & Szasz, 2001; West & Shlesinger, 1989). Hence, given that pink noise may indicate the optimal coordination vital to dynamic systems, the same things should also be true in bilingual language processing. As pink noise can be considered as a footprint of self-organization within a dynamic system (Holden, 2005), investigating its presence in bilingual lexical processing may provide an insight into multilingual minds, and help to resolve the question of whether language processing can be considered as a component-dominant or interaction-dominant process.

The present study attempts to investigate bilingual lexical processing through an ecological approach by examining data of the continuous flow of bilingual minds in a series of lexical decision tasks. By preserving the order of the reaction time, self-organizing patterns inherent in changes over time as manifested in pink noise might be observable. Moreover, the emergence of pink noise might also signal that lexical processing involves optimal coordination between body, mind and environment. Furthermore, concerning the environment, Elman (2011) argued that lexical representations reside within the contexts. This is confirmed by a single subject study
conducted by Lowie et al. (2014) which revealed that immediate linguistic history in the form of seven days L1 and L2 immersion contexts affected the scaling relation of pink noise, which signals optimal coordination of subsystems within a bilingual mind. Nevertheless, given that the human mind works in continuous flow and is sensitive to the surrounding environment at multiple time scale, it is interesting to investigate whether a very immediate linguistics experience would produce similar effects. This study, hence, is interested in seeing the dynamics of bilingual lexical processing and the effect of the immediate language use on the process. In doing so, intact time series data gathered from language use context manipulation procedures and lexical decision tasks were performed. In addition, considering that differences in initial conditions might affect the dynamic of the process, this study also focused on examining intra-individual variation in bilinguals with different L2 proficiency levels. Ultimately, applying a combination of linear and non-linear analyses on the data, the study seeks to establish if lexical processing in the bilingual minds works in a discrete manner similar to a computer, or whether it occurs in a dynamic and continuous flow like that of a river.
The chapter reviews the pertinent literature on complex dynamic system theory (CDST) perspective on the emergence of self-organizing patterns in online bilingual lexical processing as manifested in 1/f scaling relations or pink noise, which refers to a semi regulated variability pattern that indicates the optimal operative state between automatized behavior and adaptability to the changing environment (Lowie & Verspoor, 2015). Examining prior empirical findings and theoretical frameworks relevant for the study, the chapter is organized into four major sections. Section one defines Dynamyc System Theory (DST) in relation to bilingual lexical processing. Section two will subsequently discuss the notion of continuity of mind and its implication to the approach taken in the study. Furthermore, section three will illustrate the ubiquity of 1/f scaling relation, commonly referred as pink noise, in human cognition and its consequences for bilingual lexical processing. Finally, hypotheses related to the research questions are the formulated.

2.1. A Dynamic Perspective on Language Use

“All species are unique, but human are uniquest”
(Dobzhansky, 1955, p.12)

Language use has been considered the most unique ability that defines humanity. Although most species evidently interact and communicate, language evolves only in humans, and hence makes humans the ‘uniquest’ (Dobzhansky, 1955). The fact has
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raised a question of why other organisms cannot use languages the way humans do. Premack (2004) proposes that the answer to the question may dwell in the complex and recursive nature of human language, which resembles an onion or Russian doll: “one instance of an item is embedded in another instance of the same item” (p.318). Consequently, the recursion enables words in a sentence to be simultaneously widely separated yet interdependent. He continues that another explanation may reside in the fact that using a language requires mental representation, the ability to generate mental images of the perceived stimuli and produce an action conforming to it, which is exclusive to human.

However, the complexity, which is a major factor that makes human language distinctive, also poses a problem, in that it makes language difficult to learn. Generally, when the complexity becomes too difficult to manage, people cope by reducing the dynamic nature of the complex entities into named objects and thinking them as fixed ones (Larsen-Freeman & Cameron, 2008). Likewise, de Saussure made one of the earliest attempts to provide patterns and structure to help learn language despite its complexity by making distinctions between speech (parole) and language (langue), which marked a significant milestone in the development of linguistics as a modern science (de Bot, Lowie, & Verspoor, 2005; Norton & McKinney, 2011). In de Saussure’s structuralism perspective, building blocks of language structure are signs that comprise the signifier (or sound-image) and the signified (the concept or meaning), and that meaning is determined by the language system. The strong emphasis on the structure, hence labeled as structuralism, has provided a structured testable framework for the genesis of modern
linguistics. Consequently, theories in the field were predominantly built on structuralism, resulting in well-structured, hierarchical, and componential view of the language (Larsen-Freeman, Schmid, & Lowie, 2011).

Along with the wake of poststructuralist theories in the late 20th century, criticism has been leveled against structuralism for being too reductionist, in that it oversimplifies the complex nature of the language. For example, it cannot explain the complexity of social meaning, such as people may attribute different meanings for the same word based on the given context (Norton & McKinney, 2011). In other words, language in natural context is too complex to confine within rigid structures. Responding the reductionist view, Dynamic System Theory (DST) has been advocated as an alternative approach that highlights the inherent characteristics of language as a natural system which is “dynamic, complex, nonlinear, unpredictable, sensitive to initial conditions, sometimes chaotic, open, self-organizing, feedback sensitive, adaptive, and have strange attractors that are fractal in shape” (Larsen-Freeman, 2007, p.35). Consequently, embracing DST implies the need to shift from the traditional linear approach to language use into an unorthodox and non-linear one, whereby language is considered as a dynamic system.

2.1.1. Language as a Dynamic System

“Systems” can be broadly defined as group entities or parts that work together as a whole (De Bot & Larsen-Freeman, 2011). In the DST perspective, however, ‘systems’ are not merely aggregates or collection of entities, in that components within the systems interact and affect each other resulting in the emergence of a particular behavior (Larsen-
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Freeman & Cameron, 2008). Hence, the complexity degrees of systems are not determined by the aggregate number of elements, but by the characteristics of the emergent behavior: a simple system generates predictable results (e.g. the on/off lamp switch), and a complex system triggers unpredictable outcomes (e.g. the world economic system). Consequently, language is not a static object, but a contextualized product of its interaction with factors, such as the basic nonlinguistic ones (i.e. physiology, perception, processing, pragmatics, and so on) (Larsen-Freeman, 2006; O’Grady, 2008).

Furthermore, a system can be best defined by its inherent properties. Thus, understanding a dynamic system can be attempted by looking at its fundamental nature. First of all, it should be noted that the term “dynamic system” emphasizes changes over time. In addition to changes over time and the emergent properties, there are several basic characteristics inherent to a dynamic system, including sensitive dependence on initial conditions, complete interconnectedness, nonlinearity, self-organizing, and iteration (i.e. the present level of development depends critically on the previous level of development) (De Bot & Larsen-Freeman, 2011). These characteristics are prevalent in a wide range of natural systems such as a weather pattern (Lorenz, 1972), mating patterns of butterflies (Wickman, 1988), and also in the non-natural ones, such as in the patterns of the stock exchange (Ajayi & Mougoué, 1996), indicating the omnipresence of dynamic systems. Consequently, this poses a question whether these characteristics are also endemic in language use; hence, whether language can be considered as a dynamic system that changes over time.
Along with the rise of a non-linear approach to language, there has been an increase in studies confirming the notion that language is a dynamic system. Evidence from longitudinal studies has convincingly confirmed the emergent properties of language. For example, Larsen-Freeman (2006) revealed that complexity, fluency and accuracy emerge as the system adapts to a changing context in Chinese learners of English. Furthermore, research also suggests that language use involves non-linear interaction between various components, and degrees of variability may give a deeper insight to the dynamics underlying the process. For instance, a longitudinal study of a Dutch learner of Finnish revealed different patterns of connection between grower showing the changing relations between complexity measures over time (Spoelman & Verspoor, 2010). Next, the notion that language use shows self-organizing patterns is also apparent in the body of research of 1/f (pink) noise as the manifestation of a self-organizing pattern (Kello et al., 2008; Lowie et al., 2014; Lowie & Verspoor, 2015), which falls under the other section in this chapter. To conclude, the empirical evidence corresponds with the characteristics of dynamic systems, and it is fair to say that language is indeed a dynamic system. Consequently, the unpredictable nature of a dynamic system implies the need of seeing the pattern of language use in a non-canonical way, different from the predictable linear approach.

2.1.2. Dynamic Patterns of Language Use

The conundrum that lies in language processing has led to speculations about the underlying mechanism of the process. One of the classical metaphors sketched as an
attempt to comprehend the complex process is the computer analogy, in that “minds operate like serial computers, making cognition the logical ordering and manipulation of symbols, [...] in a rigidly top-down, rule governed way” (Atkinson, 2011, p.144). The computer analogy entails a componential view on language processing, in that language processing happens in discrete computer steps: input, process, and output. The simplicity of the metaphor provides a comprehensible perspective into language processing. However, criticism has been countered to the notion due to its ecological validity. Dewey (1986 as cited by Spivey & Dale, 2004), for instance, argued that “segmenting the natural life of an organism into discretely identifiable stimuli and responses is artificial and potentially misleading.” (p.88). Likewise, Van Gelder & Port (1995) proposed a dynamic approach as an alternative perspective to cognition:

“The cognitive system is not a computer, it is a dynamical system [...] the cognitive system is not a discrete sequential manipulator of static representational structures; rather it is a structure of mutually and simultaneously influencing change. Its processes do not take place in the arbitrary, discrete time of computer steps; rather they unfold in the real time of ongoing change in the environment, the body and the nervous system. The cognitive system does not interact with other aspects of the world by passing messages of commands; rather, it continuously coevolves with them” (p.3).

Based on the above notion, changes over time is at the heart of a dynamic system. Yet, even more interesting is the idea of how a system continuously coevolves with the environment as representational structures unfold over time. If this notion is true for the cognitive system, then it is assumed to be true for the language system as well. Consequently, from the dynamic perspective, representations are assembled in the
interaction of interconnected variables instead of being passively stored in strict modular computer like components.

Form DST perspective, language use is ‘soft-assembled’ in the immediate context on one level and at one time scale (Larsen-Freeman & Cameron, 2008). The term ‘soft’ is used to emphasize how the assembled elements as well as the assembly procedure may change at any point, i.e. flexible. Furthermore, Larsen-Freeman (2011) adjusted the term to describe how learners use their language resources to respond to the communicative pressures. This is especially true for L2 learners, who weave the available resources together in an online real-time response through feedback, self-organization and reciprocal causation (Larsen-Freeman & Cameron, 2008; Larsen-Freeman, 2011). The notion of soft assembly highlights the iterative nature of language as a dynamic system, in that the present condition affects the following one, and is affected by the preceding one; and as according to the idea of ‘soft-assembly’ changes and coadaptation happens over time, the end state of the system is unpredictable.

Concerning the end result of the assembly, Van Orden et al. (2009) argued that living systems are “attracted to optimal temporary states of flexible coordination, which best guarantees contextually appropriate behavior and the wellbeing of the actor (p. 641).” In other words, although the coordination during soft-assembly systems may be stochastic or chaotic in nature, systems have the tendency to self-organize in order to attain the best condition possible. This implies that, at one point, the systems will reach the critical point of self-organization to arrive at the optimal condition. Hence, before the optimal condition is met, it can be assumed that the oscillation of the variability will be
erratic, but will stabilize afterward. Consequently, the soft-assembly process cannot be plotted in a linear graph. Instead, a dynamic model is best plotted as a logistic function that produces an S-curve (Larsen-Freeman & Cameron, 2008; Lowie, Caspi, Van Geert, & Steenbeek, 2011). Overall, an S-curve can be interpreted as an initial slow change period, followed by a period of more rapid change, and then succeeded by another period of slower change. The final state of less variability indicates that the system is self-organized. Furthermore, the logistic graph can also help to visualize the unpredictable nature of language through bifurcation as shown in Figure 2.1. It can be inferred from the graph that a sudden jump or a random fluctuation might signal growth. Even more interesting is how the same pattern recurs at different levels, which intuitively contradict the observed stochastic flux. The recursive pattern is reviewed under the following subsection, and to summarize the present section, it can be concluded that language is not a static entity and variability in a system might signal soft-assembly mechanism moving toward self-organization.
2.1.3. Language Use as a Fractal

The dynamic patterns that view language use as embedded within time and space have entertained a fascinating question: “what is the shape of language trajectory in the landscape of human-using potential?” (Larsen-Freeman & Cameron, 2008, pp.108). Actually, a clue to answering the question has been given at the earlier part of the chapter: the recursive nature of human language, which makes it unique (Premack, 2004). The recursive patterns, whereby repeating patterns emerge at every scale, can also be referred as fractal, i.e. a geometric shape that is self-similar at different level (Mandelbrot, 1983). Evidently, fractals are prevalent in nature and observable in such diverse areas as economics, scientific productivity, bronchial structure and cardiac activity (West & Shlesinger, 1989). Then, if fractals are prevalent in a wide range of natural phenomena, are they also present in language use?
A condition required for any system to be considered as fractals is that it must have properties that are applicable at all levels. Zipf as cited by Larsen-Freeman & Cameron (2008) has made a groundbreaking attempt to investigate the underlying patterns that govern natural language use. According to Zipf’s law, the frequency of any word is inversely proportional to its rank in the frequency table, and hence yields fractals. More recently, a series of time-reaction experiments conducted by Holden (2002) also revealed a fractal pattern in the relations between English spellings and pronunciations. Assuming that spelling and pronunciation represent different measurement scales, which are nested in a manner loosely analogous to how centimeters are nested within meters, the inverse power law scaling distribution pattern found in the lexical decision response times provides empirical evidence of fractal patterns in language use. Given that a fractal organization provides flexibility that enables a system to change and adapt to new circumstances, its presence can be assumed as a robust indicator of a complex system.

2.2. The Flexibility of Lexical Representation in the Bilingual Mind

“... like a delicate dance with many different scores, the selection of which is being constantly negotiated while the dance is in progress, rather than in advance.”

(Savage-rumbaugh et al., 1993, p.32).

The above dance metaphor has been used to visualize language as a dynamic system (Broersma, 2011; de Bot, Lowie, & Verspoor, 2007), yet it can also elegantly describe the interactions of L1 and L2 within a bilingual mind. Given that a pair of dancers represent the elements of L1 dancing on a dance floor, they have to share the
limited space when another couple, representing L2, join the dance. Consequently, co-adaptation takes place: given the limited resources, i.e. the dance space, equal distribution of the available resources might not be attained, resulting in competition patterns between elements (Spoelman & Verspoor, 2010; Verspoor, Lowie, & Van Dijk, 2008) which can lead to inhibition. In contrast, provided that the two couples do a similar dance, movement accuracy may be enhanced by observing each other, or all the dancers may collaborate and a new complex movement patterns may emerge; thus, a facilitation effect manifested in a supportive pattern occurs. In the case of L1 and L2 interaction, this is evident in the case of inter-lingual homographs that activates both languages (de Bot et al., 2005). As described by the dance metaphor, the dynamics underlying bilingual language processing are indeed complex, and consequently difficult to grasp.

Understanding the dynamics underlying bilingual language processing is fascinating, but also difficult at the same time. Even attempts to gain insight into the process happening in multilingual minds via advanced neuroimaging technology have not contributed much to the understanding of the complex process, except that language processing is a complex interaction of various factors which supports the notion of language as a complex dynamic system (de Bot, 2008). Thus, although the technique allows linguists to see what is happening in the brain during language processing, it cannot determine the interaction patterns and dynamics underlying the process. Consequently, when the complexity of a particular phenomenon becomes too difficult to comprehend, people tend to simplify them into theories to make it easier to comprehend.
Likewise, simplification as an attempt to understand lexical processing was yielded through the use of models and metaphors.

Heavily influenced by Saussure’s structuralism, linguistic models typically consist of elements represented by boxes, causalities indicated by arrows, and hierarchical structures visualized by trees; hence, highly modular and structural in nature. Thus, these models might not be powerful enough to ideally explain systems as dynamic as bilingual language processing. De Bot (2004) even went further by suggesting that “there is no need to develop a specific model for such multilingual processing” (p. 17). Nevertheless, as the journey to yield a clear and full understanding of the interaction within and between languages in a bilingual mind is still very far to go, resorting to the available models and metaphors is a sensible step to arrive at an initial understanding of the organization of linguistic knowledge, or at least an approximation thereof (Larsen-Freeman et al., 2011).

In general, the available lexical processing models share one general view that lexical representations are stored information in a repository that behave in a passive manner and relatively insensitive to the context (Waegenmaekers et al., 2014). This is evident in the strict modular nature of Levelt’s speaking model. One of the criticisms leveled to the model points out that its rigidity implies that once information left one stage, it is not possible to return to that stage without making a loop (de Bot et al., 2005). Thus, the model assumes that lexical representations merely obey the flow of the system in a static and structured manner. De Bot’s (1992) adaptation of the model also cannot resolve the modularity issue. Likewise, Jackendoff’s (2002) Parallel Architecture also
adopts componential point of view on language processing in that syntax, semantic and phonology are product of independent generative systems, and each one is further subdivided into independent tiers. Furthermore, lexicon is considered as a part of interface components between the generative sources, and thus serves a passive role as “the store of words in long-term memory from which the grammar constructs phrases and sentences” (p.130).

In contrast, another stance of research reveals that lexical representations are flexible, in that word meaning are context-sensitive, and word interpretations are generated from detailed knowledge of words properties rather than only from a particular component. Evidences from neuroimaging studies, for example, support the notion that lexical representations are sensitive to context (Ferretti & Mcrae, 2007; Kuperberg, Paczynski, & Ditman, 2011; Lau, Holcomb, & Kuperberg, 2013). In the study conducted by Ferretti & Mcrae (2007), for instance, it was revealed that verb aspects influence the activation of knowledge, in that common locations of events (e.g. arena) are primed following verbs with imperfective aspect (e.g., was skating). The general conclusion of the study suggests the evidence of a dynamic interplay between event knowledge and the linguistic stream. Furthermore, this implies that lexical representations should not be considered as static, but highly dynamic and context dependent. Consequently, given that lexical representations are dynamic and interconnected with contexts, then “where does lexical knowledge reside?” (Elman, 2011, p.11). A radical answer to that question is that lexical representations are not necessarily stored within a lexicon as they are dynamically
present within context. Thus, Elman (2011) argues “lexical knowledge without a lexicon is possible”.

Although not specifically addressing the case of bilingualism, Elman’s (2011) unorthodox proposal on the possibility of having lexical representations without a lexicon can also be applied to bilingual lexical processing. Given that lexical representations are not strictly confined within rigid lexicon repositories, it can be assumed that L1 and L2 are basically similar (Waegenmaekers et al., 2014). Nevertheless, L1 and L2 are expected to be asymmetrical in that L1 is more deeply entrenched. This is evident in a study on L1 retrieval conducted by de Bot & Stoessel (2000) which reveals that even for a language learned as a child for a limited number of years, the lexical knowledge is still available after 30 years of non-use. Likewise, similar result was also found in lexical representation. De Bot & Lowie (2010) investigated the stability of lexical representation through a series of time reaction experiments in four very advanced Dutch learners of English, and successively investigated the intra-individual variation in lexical processing. The study concluded that lexical representations are not stable entities on which operations can be carried out, but meaning bearing structures that constantly change with use. Nevertheless, L1 reaction times were significantly faster than L2, and L2 was more strongly affected by context. These indicate that lexical representations are more stable in L1 than in L2. However, the different degrees of lexical knowledge and representation do not mean that L1 and L2 lexicon are separated. This is evident in a study conducted by Lowie, Verspoor, & Seton (2010) which focused on the influence of L1 in L2 conceptual representation. The analysis of a priming lexical decision task revealed that even very
advanced learners might acquire L2 conceptual representations differently from native speakers. This finding suggests the interference of L1 in L2 lexical processing that might indicate the existence of blended bilingual lexicon.

Furthermore, the notion of blended bilingual lexicon poses another question: how is the bilingual lexical knowledge and representation structured? It would be easier to answer the question by using the componential computer metaphor. Nonetheless, as reviewed under the previous section, a dynamic system such as bilingual lexical processing cannot be described by the discrete linear analogy. Kroll, Bobb, & Wodniecka (2006), for example, argued for the interactive nature of language processing. Focusing on bilingual language selection, they maintain that “the ability to restrict activated lexical alternatives depends on a set of factors that characterize the bilingual speakers and the context in which they are speaking” (p.132). This implies that language processing should be viewed in a space-time context, which is in line with the interaction-dominant hypothesis, whereby representations in mind are viewed as “multifarious patterns of neural activation that change continuously over time” (Spivey & Dale, 2004, p.126).

Next, Van Orden, Holden, & Turvey (2003) claimed that the interaction-dominant dynamics might be observable via examining the temporal pattern commonly referred as 1/f scaling or pink noise, which is also one of the main interests in the present study.

2.3. Pink Noise

Reaction time paradigms have been used extensively in research into human cognition as the time taken between stimulus and response is argued to be a valuable source of information about the underlying mental operation (Sternberg, 1969). One of the
pervasive phenomena regarding reaction time data is the occurrence of variability in trial-by-trial series (Holden, 2005; Van Orden et al., 2009; Wijnants, Bosman, Hasselman, Cox, & Orden, 2000). Traditionally, variability has been considered as a random error, and hence averaged away. By averaging the data points, the order of the data is disregarded. Spivey & Dale (2004) challenged the traditional view by arguing that investigation into human cognition should be psychologically ecological, in that cognitive processing should be viewed as a dynamic and continuous flow, instead of discrete componential operation. Implicit in the Spivey’s idea is the notion that the variability occurring in time series data contains valuable information about cognitive processing. Hence, a more ecological and holistic insight into bilingual lexical processing, which is also cognitive processing, can be attained by examining the flow of time series data in an intact order.

An intriguing observation from intact time series data is the prevalence of a semi regulated variability pattern that indicates the optimal operative state between automatized behavior and adaptability to the changing environment, commonly referred as a 1/f scaling, i.e. the frequency spectrum is inversely proportional to the frequency of the signal or pink noise (due to the pink color emitted by the spectrum) (Farrel, Wagenmakers, & Ratcliff, 2006; Lowie & Verspoor, 2015). The occurrence of pink noise has been argued as the manifestation of metastable patterns of coordination between brain, body and environment (Kello et al., 2008; Van Orden et al., 2009; Wijnants et al., 2000). One of the earliest studies on pink noise in human cognition was conducted by Gilden, Thornton, & Mallon (1995), which aimed at investigating the emergence of pink
noise as related to representation of spatial and temporal intervals within human cognition. In the experiment, participants were asked to repeatedly estimating fixed intervals of time. The result revealed the occurrence of pink noise which appeared as background noise in the data. This result of the study suggests that examining variability patterns that emerge from intact time series data might provide a deeper understanding on the rich dynamics of human cognition.

The simplest way to understand pink noise might be attained via visual examination of the pattern. Figure 2.2 displays an example of pink noise patterns generated from a 1024 trial series of interval estimates for a single participant (Holden, 2005). Figure 2.2.A plotted the normalized time estimates (z scores) on the y-axis against the number of successive trials. A closer look at the plot reveals a self-similar pattern as manifested in a repeated U shape along the plot. This self-similar pattern reveals fractal geometry in different time scale, which is the crux of pink noise (Van Orden et al., 2009). Next, the normalized data were subjected to spectral analysis by transforming data series from the time domain (milliseconds) into a frequency domain (Hz) through Fast Fourier Transformation, whereby amplitudes and frequencies were rendered from best-fitting sum of sine and cosine waves in the data signals (Wijnants et al., 2000). Figure 2.2.B exemplifies the results of a power spectral analysis in linear units by plotting the power/amplitudes on the Y-axis against frequency on the X-axis. The plot shows that the data are positively skewed. The amplitudes and the frequencies, then, transformed into Log 10 units, and plotted on double logarithmic axes as depicted in Figure 2.5.C. The slope is calculated to find the scaling exponent. The negatively accelerated linear relation,
with a slope less than 0 but greater than -1 is associated with pink noise. To test the significance of the pink noise, the same data were randomly reshuffled and subjected to the same procedures. Figure 2.2.E depicts the results of the spectral analysis on a linear scale. Plotting the same data on double logarithmic coordinates as displayed in Figure 2.2.F. shows that the regression slope equals to 0. Holden (2005) states that slopes with scaling relation ($\alpha \approx 0$) are associated with white noise that represent random behavior. Therefore, breaking the order of the data leads to the disappearance of self-organizing patterns. Hence, it can be inferred that fractal patterns emerging in the order time series data which evolve across multiple interdependent timescales of performance (Waegenmaekers et al., 2014).
The emergence of pink noise in a trial-by-trial data series is contradictory with the basic assumption of conventional statistics, which assumes that successive responses are independent of each other, and consequently disregards the order of the data. As demonstrated in Figure 2.2., pink noise as a form of variability pattern resides in a trial-by-trial fluctuation, and the patterns disappear when the order of the data was shuffled. The disappearance of pink noise in the randomized data shows evidence of iteration in
the process, which means that the present state is dependent on the previous state and will influence the future state (Verspoor, Lowie, & de Bot, 2008). In the light of the present study’s focus on bilingual lexical processing, the fact that the order of the data matters also supports the notion that lexical knowledge and representations are soft-assembled within contexts over time (Caspi, 2010; Larsen-Freeman & Cameron, 2008).

To date, studies investigating the presence of pink noise as a sign of a self-organizing dynamic system have agreed upon several characteristics inherent to it. First of all, pink noise is associated with self-organized criticality (SOC) (Bak et al., 1987). This means that living systems self-organize to stay near a critical state, which refers to a precise balance that allows an attractive mix of creativity and constraint whereby natural purposive behavior originates (Van Orden et al., 2003). This delicate equilibrium of SOC is represented in pink noise’s scaling exponent that falls between 0 and 1, which is right between the complete random behavior of white noise (scaling exponent ≈ 0) and over regular pattern associated with brown noise (scaling exponent ≈ 2) as presented in Figure 2.3. (Holden, 2005). The unique property is simultaneously stable and flexible, which enables a system to accommodate both familiar and idiosyncratic changes in the environment. This, in turn, leads to a balanced state of optimal coordination (Holden, 2005; Lowie & Verspoor, 2015; Van Orden et al., 2009; Waegenmaekers et al., 2014).
Figure 2.3. Idealized pink noise, or $1/f^1$ noise, which occurs between white noise and brown noise. Pink noise is associated with semi regulated behavior, while white noise represents random behavior and brown noise indicates over regulated behavior.

With regard to bilingual lexical processing, several studies have attempted to investigate the presence of pink noise in the process via time reaction experiments. Lowie et al., (2014) revealed the evidence of pink noise in a naming task in L1 and L2 over a period of 6 years. The study found a more pronounced pink noise in L1, which can be interpreted as being more coordinated. In addition, a temporary immersion in an L2 context increases L2 coordination. Similarly, Waegenmaekers et al. (2014) also found more pronounced pink noise in L1 in a series of lexical decision tasks, suggesting that L1 lexical items are more coordinated than the L1. Overall, the emergence of pink noise in lexical processing supports the notion of interaction-dominant models, in that lexical items actively self-organize rather than behave in a passive manner.
2.4. Statement of Purpose

The review of the pertinent literatures has compellingly showed the evidence for the need to approach language processing in bilingual minds as a dynamic and interaction-dominant system. There has been an increase in studies confirming that the endemic characteristics of language processing are in compliance with the nature of a dynamic system. Research evidence has revealed the emergent properties of language development, which dynamically changes over time (e.g. Larsen-Freeman, 2006; Spoelman & Verspoor, 2010). Furthermore, this emergent property might occur through soft-assembly in an online real-time processing, whereby changes and coadaptation happens over time. Therefore, the trajectory of the process is flexible to the dynamic nature of the overall system, in that the present state is always influenced by the prior one while simultaneously determine the next one (Larsen-Freeman & Cameron, 2008). The flexibility is essential for a system to adapt and attain the most optimal condition that ensure the well-being of the actor, which is referred as self-organized criticality (SOC) (Bak et al., 1987). SOC is manifested in a delicate equilibrium between over regulated and over random behavior, which enables a system to adapt to the changing environment, and observable in the presence of a fractal pattern called pink noise. A bulk of research evidence (c.f. Gilden et al., 1995; Kello et al., 2008; Van Orden et al., 2003; Van Orden, Holden, & Turvey, 2005) has demonstrated that pink noise is present in the trial-by-trial variability of time series data in an intact order, which indicates interdependence between trials.
The growing evidence for the dynamic and non-linear nature of language processing suggests a need of a new approach to bilingual lexical processing, which includes the element of continuous changes over time. One of the alternatives is by embracing the notion of continuity of mind (Spivey & Dale, 2004), which holds that process flows in a continuous fashion and each stimulus is dependent and inseparable from all other stimuli. This notion runs against the component-dominant approach which holds that human cognition works in a discrete manner resembling a computer. On the contrary, it can be argued that lexical processing, as a form of cognitive process, unfolds in a continuous flow of interdependent series analogous to a river. Thinking lexical processing as a flowing river implies the idea that lexical representations in the mind as flexible entities that flow within particular contexts, which is in line with Elman's (2011) revolutionary proposal on lexical items without a lexicon.

This study, therefore, is aimed at investigating whether lexical processing in bilingual minds can be viewed as interaction-dominant process. In order to answer the question, four hypotheses are formulated as follows

1. **Hypothesis 1 (H1)**
   Variability is expected to be present in L1 and L2. Yet, since both the lexical knowledge and lexical representation are assumed to be more stable in L1, performance in L1 is expected to be more coordinated with less degree of variability as compared to L2.

2. **Hypothesis 2 (H2)**
   Using particular language affects bilingual language processing. The effect is presumed to be more pronounced in L2 than L1 due to the assumption that lexical representation and lexical knowledge in L1 are more stable.
3. *Hypothesis 3 (H3)*  
Variability in bilingual lexical processing is expected to be present between and within individuals.

4. *Hypothesis 4 (H4)*  
Lexical processing in bilingual is expected to be dynamic, episodic and self-organizing, which is manifested in the presence of pink noise in both languages.

For the purpose of hypothesis testing, a combination of linear and non-linear approach will be applied to a series of dense reaction time data gathered from lexical decision experiments that will require participants to classify nouns into living and non-living objects. The rationale behind the choice of the procedure is to ensure the presence of semantic processing, which might reveal the natural mechanism underlying lexical processing. In addition, a context manipulation procedure will be performed prior to each lexical decision task to simulate a particular language use context. Finally, the order of the data obtained from the experiments will be preserved to examine the changing variability over time.

Furthermore, a linear approach will also be employed in the data analysis. This might seem counterintuitive with the objective of the study that highlights the dynamic nature of bilingual lexical processing. Linear statistics might not provide a comprehensive picture of the dynamics of the system. On the other hand, just like a still photograph can somehow capture a picture of a dynamic entity (e.g. river), the linear approach might offer a different perspective on the matter. Combining the two approaches, then, is presumed to
provide a complete and comprehensive answer to the research question. A detailed overview of the methodology, including the data analysis procedures is described under Chapter 3.
CHAPTER 3

METHODOLOGY

This chapter introduces, and contains a discussion of, the methodological approach and experimental design best suited to examine the hypotheses stated in chapter 2. An overview of the experimental design and analyses is also presented.

3.1. Participants

Participants for this study were 4 Indonesian second language learners of English enrolled in international master programs in the University of Groningen. All participants were advanced learners of English. Furthermore, all of them were born and raised in Indonesia, where English is spoken as a foreign language, and speak Bahasa Indonesia as their mother tongue. In addition, they had spent approximately a year in the Netherlands, where English is ubiquitous in the everyday lives. The majority of the participants were female (F=3, M=1), with the age ranged from 27 to 32 years. All participants were right-handed and had normal or corrected vision.

3.2. Materials

3.2.1. Language Usage Context Manipulation

To establish whether prior contexts of language use influence the dynamic of lexical processing in bilinguals, two types of context manipulation conditions were conducted: L1 and L2 context manipulations. In the current study, both L1 and L2 priming was presented prior to the lexical decision task, and were structured in three consecutive
sections. The first section consisted of a cloze test based on audio stimuli of authentic news both in L1 and L2 played three times. The cloze tests combined with listening tasks were chosen to ensure that participants notice the stimuli and actively processed the input; hence simulated linguistic experience could be obtained. During the first listening task, the participants were required to listen closely to the stimuli. During the second listening exercise, they were asked to fill in a cloze in which 60% of the words were removed, and the third listening was allotted for checking answers. The average duration of the audio file was 2 minutes and 30 seconds; hence, the overall immersion time to the stimuli was approximately 7 minutes and 30 seconds in average. The second task was a comprehension task comprising of 5 open questions related to the given audio stimuli, requiring the participants to answer orally. Finally, the last task was a productive task whereby participants were asked to retell the news in their own words. Incorporating three different tasks that required participants to actively process the input was aimed at ensuring noticing (Wijnants et al., 2000); hence, the desired condition could be optimally attained.

With regard the sequence, the L1 and L2 context manipulation procedures were alternately paired with lexical decision tasks as tabulated in table 3.1.

<table>
<thead>
<tr>
<th>Session</th>
<th>Context manipulation</th>
<th>Lexical Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L1: Bahasa Indonesia</td>
<td>L2: English</td>
</tr>
<tr>
<td>2</td>
<td>L1: Bahasa Indonesia</td>
<td>L1: Bahasa Indonesia</td>
</tr>
<tr>
<td>3</td>
<td>L2: English</td>
<td>L2: English</td>
</tr>
<tr>
<td>4</td>
<td>L2: English</td>
<td>L1: Bahasa Indonesia</td>
</tr>
</tbody>
</table>
3.2.2. Lexical Decision Task

To investigate whether patterns of SOC manifested in 1/f scaling relations exist in bilingual language processing, a series of lexical decision tasks were developed in E-prime (Psychology Software Tools Inc., 2012). Specifically, the lexical decision tasks required the participants to categorize stimuli, in the form of concrete nouns, into either living or non-living things. The categorizing task was chosen instead of a word naming task as in Lowie, Plat, & de Bot (2014) study because it required the participants to semantically process the words. The L2 word list was adapted from Oxford Picture Dictionary (Parnwell & Burns, 1993). The L1 word list was developed by translating the L2 list into Bahasa Indonesia. Each list consisted of 572 items. Since spectral analysis requires a trial series with a power of 2 ($2^9 = 512$ in the current study), presenting 572 items resulted in a scant buffer of 60 items. In order to prevent semantic priming effects (de Bot et al., 2005), the words were first randomized using “ran” function in Microsoft Excel 2010. The same randomized list was then presented to all participants. Furthermore, adjacent items, which were closely semantically related (e.g. *firefighter* and *fire extinguisher*) were manually altered. The stimuli were presented sequentially and the order of the words for all sessions and all participants were maintained the same to enhance the comparability of the data. Moreover, the stimuli were presented in a fixed order to ensure the same set up for all participants. The overview of the lexical decision experiment structure is presented in Figure 3.1.
After the context manipulation procedures, participants were given a break. Subsequently, before each actual lexical decision task, a practice session consisting of 10 items was performed to ensure that they comprehended the instruction. On each trial, a fixation signal became visible for 500 ms., followed by a concrete noun typed in lower case, black Courier (18 points) displayed in the center of a white background. Participants were asked to categorize the noun into either non-living or living things groups as quickly as possible, by means of pressing the “1” or “9” key on a QWERTY keyboard. Each response was followed by a fixed 500 ms. inter trial interval after which the fixation signal of the subsequent trial became visible. Each session of the lexical decision task took approximately 30 minutes in average.
3.3. Procedure

Prior to the experiments, participants filled out a C-test to measure their proficiency in L2. C-test is a modification of a cloze procedure that requires participants to complete several incomplete texts, to which “the rule of two” has been applied, i.e. the second half of every second word has been deleted. This test has been seen as a reliable measure for general language proficiency (Dornyei & Katona, 1992). Regarding the scoring, only completely correct answers were awarded scores. After that, each participant was tested individually in a sound proof room to minimize any distraction. Prior to the lexical decision task, the context of language use was manipulated. Participants performed a series of productive and receptive tasks either L1 or L2. Accordingly, the context manipulation tasks were coupled with L1 or L2 tasks as outlined in table 3.1. After a short break, the lexical decision tasks were performed. A trial consisting of 10 items was presented before each session to ensure that participants understood the instruction. Following a short break, 572 items were presented. During the lexical decision tasks, the participants were suggested to keep their index fingers on the “1” and “9” button to ensure a quick response. The four sessions were conducted on four different days with a minimum of three days and a maximum of seven days in between sessions. Participants received a small amount of financial reward for participation.

3.4. Analysis

3.4.1. Data Preparation

Prior to the linear and non-linear analyses, data were prepared by trimming and detrending the raw data following the procedures as exemplified by Holden (2005). First,
extreme values that would likely distort the outcome of a fractal analysis were removed in two steps: first, reaction times that were shorter than 200 ms or greater than 3,500 ms were excluded. After that, the series mean and standard deviation were calculated. Then, reaction times, which were 3 SDs away from the series mean, were removed. To preserve the order of the time series as intact as possible, the deleted spaces were “closed up” by moving up the immediate neighbors of the deleted data. Next, as a dispersion analysis performed in the study requires an integer power of 2 (e.g., $2^9 = 512$) numbers of observations, the remaining data points were truncated by eliminating initial observations. In the present study, each time series data were truncated into 512 observations in length, out of the 572 original observations. The trimmed data could then be subjected to linear analyses. In addition, to prepare the data for the spectral and dispersion analyses, a detrending procedure was done by removing linear and quadratic trends to avoid future bias. Finally, the data were normalized to have a mean of zero and a variance of one by transforming the data points into z-scores, which were calculated by subtracting the series’ mean from each observation and dividing each of them by the series standard deviation (SD).

3.4.2. Linear Analysis

Several types of linear analyses were performed on the time series data to verify the formulated hypotheses. First, to investigate the stability/flexibility of lexical representation, the Coefficient of Variation (CV) for each trial series was calculated by dividing the standard deviation (SD) with the mean reaction times (RT). Therefore,
\[ CV = \frac{SD}{Rt} \]. The assumption, which was based on (de Bot & Lowie, 2010), was that “a reduction in the reaction time, proportionate to the reduction of the latencies themselves would reflect a general speeding up of the system, while a disproportionate change of the variability in relation of the latencies would reflect a change in the balance of automatic and controlled underlying processes” (pp.121). In addition the correlation between subjects over items was also calculated, with the assumption that high correlations between subjects was assumed to represent stable and fixed representation. Furthermore, repeated measures ANOVA was also used to determine the main effect of prior language use contexts within individuals, with significance value (\( \alpha \)) was set at 0.05.

### 3.4.3. Non-linear Analysis

In order to investigate the presence of pink noise in the trial series, two unorthodox non-linear data analysis methods were applied, namely Power Spectral Density Estimation and Standardized Dispersion Analysis. Both of the methods are described as follows.

**Power Spectral Density Estimation (PSDE)**

One way to obtain information on the correlational structure of fluctuations in a time series data is by conducting spectral analysis techniques. The present study employed a particular spectral analysis method referred as power spectral density estimation (PSDE) to yield power spectrum of prepared trial series. PSDE is best described as a process of “[decomposing] a trial series into a set or regular oscillations, component waves with particular frequencies and amplitude” (Holden, 2005, pp.290). In doing so, the prepared data were subjected to Fast Fourier Transformation (FFT), which converts the time
domain the successive trial series to the frequency domain, whereby amplitudes and frequencies were rendered from best-fitting sum of sine and cosine waves in the data signals (Wijnants et al., 2000). This procedure yielded a set of coefficients characterizing relative amplitudes of wave forms, ordered from lowest to highest frequency, which is called power spectrum. Next, to identify fluctuations over frequency, a data windowing procedure was performed by breaking a single long 512-trial series into several shorter, overlapping series of response time. The individual power spectra derived from each segment were then averaged. In the current study, 63 estimates were yielded from each data series calculated (which followed the parameter of 0.125 of numbers of observation. In this case, 0.125 X 512 = 64. The first estimate always equals to 0 and was excluded, which yielded 63 estimations in total). In the present study, PSDE values were calculated using MATLAB scripts following (Holden, 2005), and generated 63 power and frequency spectra in log 10 units.

Next, the results of PSDE were plotted on linear scales (in line charts and scatter plots), as depicted in Figure 2.2. The approximately linear relation (slope) between power and frequency spectrum in the log-log domain was associated with an inverse power-law scaling relation. To establish whether a slope falls within the range of pink noise, categories as illustrated in Figure 2.3. were applied. A slope of 0 is associated with independent sources of random variation, called white noise, while a slope of less than 0 and greater than -1 is the domain in pink noise, which is the one of the main interests of the present study. In addition, a slope of less than -1 is associated with brown noise,
which signals strictly regulated behavior (Holden, 2005). Hence, in the current study, slopes with scaling exponent \((1/f^\alpha)\) where \(0 < \alpha < 1\) were categorized as pink noise.

**Dispersion Analysis**

A more accurate technique to gauge the fractal dimensions of time series data is a dispersion analysis by estimating the change of variability due to changing sample sizes, and resulting in Fractal Dimension (FD) values. A standardized dispersion analysis (SDA), which calculates FD from normalized data instead of the raw one, was used in the present study due to its accuracy (Holden, 2005). Basically, SDA is performed by repeatedly resampling the trial series using sampling units of different sizes (bins) to estimate the fractal dimension of time-series. In the current study, the 512 normalized observations in each trial series were repeatedly resampled into 8 bins. The standard deviation for each bin was calculated. The SDs and bin sizes were then transformed into Log 2 units. The log units were then plotted to calculate the slope. The three largest bins were excluded from the calculation to avoid bias. Next, FD was calculated following the formula of: 

\[
FD = 1 - \text{slope.}
\]

A result than falls within the range of 1.2 to 1.5 is associated with pink noise (Waegenmaekers et al., 2014), while FD which is greater than 1.5 is inferred as a white noise. In addition, FD can also be calculated from PSDE, using the formula

\[
FD = 1 + \frac{(S+1)}{2},
\]

where S denotes the spectral slope of the log-log regression line. In the current study, a MATLAB script was used to calculate SDA, which was then plotted using SPSS 22.0. The occurrence of pink noise is established when FD derived
from either PSDE or SDA was between 1.2 and 1.5. It should be noted, however, that SDA yields a more accurate estimation than PSDE (Holden, 2005).

Finally, to test the significance of pink noise, each original trial series was reshuffled to generate surrogate series using Poptools (Hood, 2010) in Microsoft Excel 2010. Five surrogate series were generated for each trial series data. Next, the spectral slope for each surrogate series was calculated and averaged. When the slope of the original series is within the range of pink noise and more than 3 SD away from the mean of surrogate series slopes, the emergence of pink noise is significant (Holden, 2005).
CHAPTER 4

RESULT

The time reaction data from a series of lexical decision tasks which involves four advanced Indonesian learners of English were subjected to linear and non-linear analyses. Of the original 572 responses obtained from each session, 512 \( (2^9) \) data were selected following Holden (2005): extreme values which are less than 200 ms. and greater than 3,500 ms. Data which were 3 SD beyond the mean in both directions were excluded. The remaining data were then truncated into 512 reaction time data. Furthermore, for the spectral analyses, data were detrended and normalized. A more detailed explanation on the data preparation and analysis procedures can be found in section 3.5.

The remaining part of the chapter proceeds as follows: the first section presents the result of the linear analyses, which includes descriptive analyses, correlation and the repeated measures of ANOVA. Subsequently, the second section displays the result of spectral analyses to investigate the presence of pink noise in the time series data, which consists of Power Spectrum Density Estimation (PSDE), Standard Dispersion Analysis (SDA) and Fractal Dimension (FD) calculation. The result of the significance test using a randomizing procedure (Holden, 2005; Waegenmaekers et al., 2014) is also reported in this chapter.
4.1. Linear Analyses on Response Time Data

Four Indonesian advanced learners of English performed a series of lexical decision tests both in L1 (Bahasa Indonesia) and L2 (English) with manipulated contexts. For the purpose of linear analyses, the truncated time series data which consisted of 512 responses for each session were used. The resulting means, SDs and coefficients of variance (CV) for L1 and L2 in each context manipulation are presented in the following table 4.1., and table 4.2.

| Table 4.1. Means, SD and CV for L1 (Bahasa Indonesia) in each context manipulation condition |
| --- | --- | --- | --- | --- | --- |
| Bahasa Indonesia (L1) | Part. 1 | Part.2 | Part.3 | Part.4 |
| L1 context | L2 Context | L1 context | L2 Context | L1 context | L2 Context | L1 context | L2 Context |
| Mean | 719.72 | 786.88 | 636.79 | 689.71 | 599.38 | 566.16 | 792.56 | 664.48 |
| SD | 184.14 | 296.59 | 114.51 | 148.24 | 149.01 | 110.56 | 257.67 | 171.09 |
| CV | 0.26 | 0.38 | 0.18 | 0.21 | 0.25 | 0.20 | 0.33 | 0.26 |

| Table 4.2. Means, SD, and CV for L2 (English) in each context manipulation condition |
| --- | --- | --- | --- | --- | --- |
| English (L2) | Part. 1 | Part.2 | Part.3 | Part.4 |
| L1 context | L2 Context | L1 context | L2 Context | L1 context | L2 Context | L1 context | L2 Context |
| Mean | 906.04 | 741.81 | 1001.47 | 808.59 | 801.10 | 647.34 | 1148.70 | 736.96 |
| SD | 381.55 | 227.61 | 332.63 | 225.65 | 285.61 | 171.75 | 457.10 | 238.22 |
| CV | 0.42 | 0.31 | 0.33 | 0.28 | 0.36 | 0.27 | 0.40 | 0.32 |

It can be inferred from the table that latencies for L2 were consistently higher than those for L1. Likewise, the CVs and SDs are generally higher in L2 for both context manipulation conditions. In addition, with regard the context manipulation conditions, whilst higher latencies for all participants were observed when L1 manipulation context was paired with L2 lexical decision (i.e. context language was different from language used in lexical decision task), no such pattern was found in L1, which appear to be more random.
Furthermore, for the purpose of examining the variation in reaction times for items between participants, correlations were calculated as presented in table 4.3. The result showed that correlations between participants were very low, which may indicate that there are no consistent reactions to items, but rather variation between individuals.

| Table 4.3 Correlations between participants over items |
|---------------------------------|---|---|---|---|
| English/ Bahasa | P1 | P2 | P3 | P4 |
| P1 | - | 0.12** | 0.06** | 0.03 |
| P2 | 0.12** | - | 0.26** | 0.21 |
| P3 | 0.06** | 0.26** | - | 0.24** |
| P4 | 0.03 | 0.21** | 0.24** | - |

To get more detailed information on variability within individuals, data from two participants were analyzed separately. The two participants were chosen based on the gaps in proficiency level: participant 1(P1) with the highest L2 proficiency in the group and participant 4 (P4) with the lowest L2 proficiency level in the group. Prior to a more detailed examination of each participant, an independent sample t-test was performed to see whether significant differences between the two participants exist. The t-test revealed that there are significant differences on the two participants’ latencies in three sessions. The participant with a higher proficiency level showed shorter latencies in two sessions: session one which involves L2 lexical decision after L1 context manipulation task ($M = 906.04, SE = 16.86$) and session two on L1 decision task after L1 context manipulation task ($M = 719.72, SE = 8.14$). These differences were significant ($t(1022) = -0.922; p < 0.001$ for session 1, and $t(1022) = -5.20; p < 0.001$ for session 2). Conversely, the participant with lower L2 proficiency displayed faster reaction times in session 3.
where they were required to do an L1 lexical decision task after L2 context manipulation ($M = 664.48, SE = 7.56$). This difference was significant ($t(1022) = 8.09; p < 0.001$). The participant with lower L2 proficiency also responded faster during an L2 lexical decision task after L2 context manipulation task ($M = 736.96, SE = 10.06$), but this different was not significant ($t(1022) = 0.739; p > 0.05$).

Although the independent sample t-test confirmed the effect of proficiency level on latencies across different context manipulation conditions, it might not explain the variation between sessions, languages and proficiency level. One way to compare the variation is by examining the standard deviations (SD), and coefficient of variation (CV), which is calculated by dividing SD with mean RT. CVs enable a better analysis of variation since it shows SDs changes in proportion to the mean RTs. Table 4.4 shows the mean RTs, SDs and CVs of the four sessions for both participants with higher and lower L2 proficiency level.

<table>
<thead>
<tr>
<th>Language/Context</th>
<th>Higher Proficiency Level</th>
<th>Lower Proficiency Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT</td>
<td>SD</td>
</tr>
<tr>
<td>English – Indonesia context</td>
<td>906.04</td>
<td>381.55</td>
</tr>
<tr>
<td>Indonesia – Indonesia context</td>
<td>719.72</td>
<td>184.14</td>
</tr>
<tr>
<td>Indonesia – English context</td>
<td>786.88</td>
<td>296.59</td>
</tr>
<tr>
<td>English – English context</td>
<td>741.81</td>
<td>227.61</td>
</tr>
</tbody>
</table>

It can be observed from the table that the CVs for both participants are the highest when an L2 lexical decision task was performed after L1 context manipulation. Next, the lowest variation for the more proficient participant was found when L1 lexical decision
task performed after L1 context manipulation. Interestingly, the lowest variation for the least proficient participant was found when L1 lexical decision task conducted after L2 context manipulation condition. Even more fascinating is the fact that gaps in variation between the two participants appeared to fade when L2 lexical decision task was presented after L2 context manipulation. This may lead to an interesting discussion on the nature of lexical representation in L1 and L2 which falls under the discussion section.

To further investigate the possible effect of contexts in latencies for both languages, two repeated measures of ANOVA with language and context as variables were performed for both the more proficient participant and the less proficient participant. The repeated measures of ANOVA for the more proficient participant showed that the main effect of context was found to be significant, $F(1,511) = 13.66, p < 0.01$. Furthermore, the interaction between context and language was also found to be significant, $F(1,511) = 96.72, p < 0.01$. A follow up paired sample t-test on the data confirmed the effect of context. There was a significant difference in the latencies in L1 lexical decision with L1 context manipulation ($M = 719.73, SD = 184.14$) and with L2 context manipulation ($M = 786.88, SD = 296.59$); $t(511) = -4.34, p < 0.01$. Similarly, a significant effect was also found in L2 lexical decision task, whereby there was a significant difference in latencies after L2 context manipulation ($M = 741.81, SD = 227.61$) and after L1 context manipulation ($M = 906.04, SD = 381.55$); $t(511) = 8.34, p < 0.01$. Thus, it can be inferred that reaction times were faster when the participant used the same language as the language used in the lexical decision tasks. The interaction is illustrated in Figure 4.1.
Similarly, a significant main effect of context was also found in the less proficient participant, $F (1,511) = 417.59$, $p < 0.01$. The interaction between language and context was also significant, $F (1,511) = 122.63$, $p < 0.01$. Reaction time for L1 was consistently faster than for L2. A follow up paired-sample t-test supported the significant effect of context manipulation on latencies. There was a significant difference in L1 reaction times when context was manipulated for L1 ($M = 792.26$, $SD = 11.39$) and when context was manipulated for L2 ($M = 664.48$, $SD = 7.56$); $t (511) = 9.67$, $p < 0.01$. This also implies that the overall latency was shorter when an L2 context manipulation was presented. The same significant difference was also found in L2 reaction time. The reaction time was faster when L2 context manipulation was presented ($M = 736.96$, $SD = 10.53$) than when L1 context manipulation was performed ($M = 1148.69$, $SD = 20.20$); $t (511) = 18.39$. An

**Figure 4.1.** Mean RT’s for the interaction between Context and Language for the more proficient participant
interesting pattern was observable in the interaction between context and language as illustrated in Figure 4.2.: while the reaction times for L2 lexical decision tasks were faster when context manipulation in similar language was performed, the same thing did not occur in L1 lexical decision tasks.

![Mean RT's for the interaction between Context and Language for the less proficient participant](image)

**Figure 4.2.** Mean RT's for the interaction between Context and Language for the less proficient participant

4.2. Spectral Analysis

4.2.1. Power Spectral Density Estimation

A series of Fast Fourier Transformation (FFT) analysis, then, were performed to the normalized data, resulting in 63 pairs of Fourier frequency and power for each session. Next, the outcomes were plotted with power against frequency on a log-log scale, and the slopes were calculated. Figure 4.3.A. illustrates a reaction time series from a participant in a session. Subsequently, the outcomes of the spectral analysis are visualized in Figure 4.3.B on linear scales and in Figure 4.3.C. on logarithmic scales.
Figure 4.3. The result of power spectral density estimation derived from a participant data. The 512 normalized reaction time data series were plotted against trial number; the circled areas show repeated U patterns, which indicates fractal patterns (A). The frequency was plotted against power in picture B, and the same results were converted into log 10 units as plotted in picture C.
A quick visual inspection of the graph revealed the presence of pink noise in the time-series data. A closer examination on figure 4.3.A. showed repeated U patterns (as shown by the circled areas), which indicate the existence of fractal patterns. Hence, it might be presumed that the data were not completely random. This assumption was supported by figure 4.3.B. When the spectral frequency and power values yielded from the FFT were plotted, a skewed pattern was observed, which might show that spectral power tended to be lower in higher frequency. Furthermore, when the power and frequency values were transformed into log 10 units to obtain symmetric distribution and the spectral slope was calculated, the value of the slope confirmed the presence of pink noise in the data with scaling exponent (α) of 0.26 which falls within the range of $\frac{1}{f^\alpha}$ scaling relation where $0 < \alpha < 1$. It should be noted that the negative sign of the slope was transformed into positive to indicate the scaling exponent (i.e. the positive counterpart of the slope). The same procedures were performed to all time reaction data from 16 sessions. The PSDE from all sessions (as can be found in Appendix D), confirmed the presence of pink noise in almost all sessions. The slopes of each individual participant on four different sessions are summarized in Table 4.5. In addition, Means and SDs for each session are also given.
The PSDE results showed that almost all slopes have a scaling exponent (positive counterpart of the slope) within the range of pink noise \( \frac{1}{f^\alpha} \) where \( 0 < \alpha < 1 \). The steepest slopes for the means was found in session 3, in which participants performed L1 lexical decision task in an L2 context, whereas the least steep slopes were found in session 1 (when participants did L2 lexical decision task in L1 context), and session 4 (when participants performed L2 lexical decision task in L2 context). Nevertheless, at a glance, differences between the slopes in the four sessions are relatively small. Further analyses were carried out the test whether the occurrences of the pink noise in the data were significant. The result of the significance test is reported under section 4.2.3.

### 4.2.2. Standardized Dispersion Analysis and Fractal Dimension

In addition to PSDE, standardized dispersion analyses (SDA) were also performed in MATLAB following (Holden, 2005). This was done by repeatedly resampling trial series using sampling units of different sizes. The outcomes were then plotted bin sizes against SDA values on double logarithmic scatter plots as shown in figure 4.4. The three largest
bins were excluded in the calculation to avoid bias. Fractal dimension, then, was calculated according to the following formula: \( FD = 1 - S \), where \( S \) denotes slopes. In addition, PSD values can also be used to calculate FD based on the formula: 
\[ FD = 1 + \left( 1 + \frac{1+S}{2} \right)^2 \]
where \( S \) denotes slope. The results yielded from the calculation were plotted in figure 4.4. FD values fall within the range of 1.2 and 1.5 are associated with pink noise.

Figure 4.4. The SDA result of one participant was plotted power against bin size in log 2 units

Figure 4.4. illustrates SDA on a participant data in a double logarithmic axes. The slope was at \(-0.49\), which yielded FD of 1.49. This value is still within the range of pink noise, which falls between 1.2 to 1.5. Therefore, it can be inferred that fractal patterns were present in the data. Nevertheless, the FD value was very close to the white noise criteria (0.5), which suggest that the spectrum was somehow ‘whitened’. However, as dispersion
analysis tends to lose its accuracy in time series data that display very strong interdependence (Holden, 2005), interpretation on the values should be done cautiously. SDA were performed to data gathered from all sessions, and can be found in appendix F. The summary of FD values calculated from both SDA and PSD were tabulated in Table 4.6.

<table>
<thead>
<tr>
<th>Table 4.6. Mean FD and SDs calculated from Spectral Analysis and SDA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>FD Session 1: L2 task in L1 context</td>
</tr>
<tr>
<td>FD Session 2: L1 task in L1 context</td>
</tr>
<tr>
<td>FD Session 3: L1 task in L2 context</td>
</tr>
<tr>
<td>FD Session 4: L2 task in L2 context</td>
</tr>
</tbody>
</table>

Table 4.6 illustrates that the mean FDs calculated from SDA are slightly higher than those derived from PSD. The FD calculated from SDA shows that lower FD (i.e. more pronounced pink noise) are found after the participants used the same language as the one used in the lexical decision tasks. This was particularly observable in L2, whereas L1 usage prior to L1 lexical decision tasks yielded FD that fell within the white noise range associated with random behavior.
4.2.3. Significance Test

One method to test the significance of pink noise is by randomly reshuffling the order of original trial series for several times, and computing the spectral slope of each surrogate series. The occurrence of pink noise is considered to be significant when the slope of the original series is within the range of pink noise and more than 3 SD away from the mean of surrogate series’ slopes (Holden, 2005). In this study, the data from each series were reshuffled five times (following Waegenmaekers et al., 2014). Figure 4.5. depicts an example of the spectral analysis result of a randomized data series of a participant, whose the original response times were illustrated in Figure 4.3.

Figure 4.5.A. illustrate the randomized normalized reaction data against the trial number. Compared to the original data depicted in figure 4.3.A, the repeated U shapes faded, which indicates that the fractal pattern might no longer exist. Figure 4.5.B also confirmed the absence of fractal pattern in that the dispersion of the data showed random dispersion. The calculated slope as depicted in Figure 4.C. showed the presence of white noise associated with complete random behavior ($\alpha \approx 0$).
Figure 4.5. The result of power spectral density estimation derived from a randomized participant data. The 512 normalized reaction time data series were plotted against trial number (A). The frequency was plotted against power in picture B, and the same results were converted into log 10 units as plotted in picture C.
Table 4.7. *Summary of significance test.*

<table>
<thead>
<tr>
<th>Session</th>
<th>Mean Original slope</th>
<th>Mean 5 surrogates slope</th>
<th>SD surrogates slope</th>
<th>Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : L1 context-L2 task</td>
<td>-0.11</td>
<td>0.024</td>
<td>0.034</td>
<td>Yes</td>
</tr>
<tr>
<td>2 : L1 context-L1 task</td>
<td>-0.13</td>
<td>0.009</td>
<td>0.031</td>
<td>Yes</td>
</tr>
<tr>
<td>3 : L2 context-L1 task</td>
<td>-0.16</td>
<td>-0.024</td>
<td>0.016</td>
<td>Yes</td>
</tr>
<tr>
<td>4 : L2 context-L2 task</td>
<td>-0.11</td>
<td>0.011</td>
<td>0.014</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 4.7. summarizes the result of the significance tests. It can be inferred that the spectral slopes for all sessions were more than 3 SD away from the mean of surrogate series. Hence, it can be said that the variability patterns found in the time series data are significantly associated with pink noise.
5.1. Discussion

This study was aimed at investigating whether lexical processing in bilingual minds can be viewed as an interaction-dominant process. Four hypotheses concerning lexical processing in bilingual minds were formulated in section 2.4., which includes the variability of L1 and L2 representation, effects of very immediate linguistic experiences, variability between and within individuals and emergence of pink noise in bilingual lexical processing. To test the formulated hypotheses, results yielded from data analysis were discussed in this section.

5.1.1. Flexibility of L1 and L2 lexicons in Bilinguals

The first hypothesis touched upon the flexibility of L1 and L2 lexicons in bilingual minds. Considering the fact that language use is a dynamic system (c.f. De Bot & Larsen-Freeman, 2011; De Bot, Lowie, & Verspoor, 2007; Larsen-Freeman & Cameron, 2008; Larsen-Freeman, 2011), variability is assumed to exist both in L1 and L2. Nevertheless, processing of lexical items is expected to be less flexible in L1 as it is more deeply entrenched. Unsurprisingly, the data analyses revealed that response times in L2 lexical decision tasks were consistently slower than in L1 lexical decision tasks, which showed more stable behavior in L1. To establish whether lexical processing is a component-dominant or interaction-dominant system, the flexibility of lexical representation was examined by analyzing CV and correlation between items as exemplified by de Bot &
Lowie (2010). When items have stable and fixed representations, which is in favor of component-dominant models, correlation between subjects were assumed to be high. In contrast, low correlation is associated with more flexible representations. This study found that response times for L2 were consistently slower than those for L1. In addition, CVs for L2 were also higher than L1, which suggested that L2 was less stable than L1. Furthermore, further analysis on the correlations of reaction times between participants was found to be low. Thus, it can be inferred that lexical items do not have stable and fixed representations. A similar finding was also reported by Lowie, Plat, & de Bot (2014) who also found similar pattern even in a very advanced bilingual. This supports Elman's (2011) proposal that lexical representation are not necessarily stored within lexicon, but dynamically present within context. Lexical representation, therefore, is flexible and adaptive.

The finding of more stable representation and better coordination in L1 was also supported by spectral analyses. The PSDE results confirmed the occurrence of scaling exponents within the range of 0 to 1, which is associated with pink noise. As pink noise is regarded as an indicator of self-organizing system (c.f. Bak, Tang, & Wiesenfeld, 1987; Van Orden, Holden, & Turvey, 2003), it can be assumed that bilingual lexical processing is a self-organizing process. Consequently, given that lexical items are continuously self-organizing in bilingual minds, lexical representations in both language can be viewed as flexible (c.f. de Bot & Stoessel, 2000; de Bot & Lowie, 2010; Waegenmakers et al., 2014.). Overall, the hypothesis that variability occurs in L1 and L2, and lexical representations is more stable in L1 than L2, was verified.
5.1.2. The Effect of Language Use on Bilingual Lexical Processing

The second hypothesis concerns the effect of using a particular language on lexical processing. In the present study, contexts prior to lexical decision tasks were manipulated to simulate both L1 and L2 contexts by asking participants to do a series of receptive and productive tasks either in L1 or L2. Each context manipulation task was aimed at stimulating very immediate linguistic experience in a particular language by requiring participants to use four language skills (i.e. speaking, listening, reading and writing) in approximately 10 - 15 minutes. Pairing the context manipulation for language use and the lexical decision tasks were presumed to be an effective procedure to obtain information essential to test the hypothesis of whether a particular language use affects bilingual language processing.

Data analysis confirmed that context/language use has an effect on bilingual lexical processing, a descriptive analysis on the time reaction data revealed that response times were consistently faster for L1 tasks than for L2 regardless of the context of prior language use. Furthermore, slower responses were consistently found when L1 usage proceeds L2 lexical decision tasks. Nevertheless, this pattern was not found in L1 lexical decision tasks, which appeared to be independent of prior language use. Similarly, spectral analysis also suggested that more pronounced ‘pink noise’, as a sign of more coordinated behaviors, was found after participants using L2 before L2 lexical decision tasks. In contrast, L1 usage prior to L1 lexical decision tasks yielded FD which belonged to ‘white noise’ category, which indicated a random behavior pattern. Therefore, it can be
inferred that L2 was more sensitive to the effect of language use, whereas L1 appeared to be unaffected by the very immediate linguistic experience.

The result of the study confirmed the findings of previous research, which argues that lexical processing is sensitive to language use (c.f. Ferretti & Mcrae, 2007; Kuperberg, Paczynski, & Ditman, 2011; Lau, Holcomb, & Kuperberg, 2013; Lowie, Plat, & de Bot, 2014). In particular, the effect of language use on lexical processing supported the finding of previous study conducted by (Lowie et al., 2014) which revealed that intensive immersion in a second-language context leads to a more coordinated behavior of that same language. Yet, the same result was not found in L1, which showed random behavior after the usage of similar language. The possible explanation for the differences between L1 and L2 with regard to very immediate linguistics experience might be due to the asymmetrical L1 and L2 lexical knowledge and representation, in that L1 is more deeply entrenched than L2 in bilingual minds (cf. de Bot & Stoessel, 2000; de Bot & Lowie, 2010). Therefore, L1 lexical items are more coordinated, and less flexible as compared to those of L2. Consequently, the more stable lexical representations are less sensitive to contexts. The finding also supports the notion that L1 lexical knowledge is still available even after a long period of non-use (de Bot & Stoessel, 2000). Furthermore, the idea that language use has an impact on language processing verifies the interaction-dominant hypothesis, in that lexical processing should not be viewed as a discrete process as it is affected by multifarious patterns that change over time (Spivey & Dale, 2004). Overall, the hypothesis that using particular language affects bilingual language processing is verified. Moreover, the assumption that the effect is more pronounced in L2
than L1 is also confirmed, indicating that L1 is generally more stable and relatively more independent of prior linguistics experiences than L2.

5.1.3. Variability Between and Within Individuals in Bilingual Lexical Processing

The third hypothesis of the study is concerned with whether there is variability in bilingual lexical processing between and within individuals. The analysis on the reaction time between participants showed low correlations, which indicates flexible lexical items. The low between participants correlation might indicate that variation occurred within individuals. Therefore, it is interesting to investigate whether variability also occurred within individual subjects. To investigate this, two subjects with highest gap of L2 proficiency level as measured by L2 C-test, were analyzed separately. An independent sample t-test performed on the two participants confirmed that the participant with a higher L2 proficiency level responded faster in L2 lexical decision tasks with no prior L2 usage \( t(1022) = -0.922; p < 0.001 \). Nevertheless, there was no significant difference between the two participants when L2 lexical decision tasks were presented after performing context manipulation procedures in L2 \( t(1022) = 0.739; p > 0.05 \). The difference in the result might show that using similar language prior to L2 lexical decision task might affect the less proficient participant’s lexical coordination. Likewise, the CV analyses for both participants showed the highest variability when an L2 lexical decision task was performed without previously using the same language. Unsurprisingly, variability was lowest in L1 lexical decision tasks after using the same language, which verifies the notion that L1 has a more stable representation. Interestingly, the gaps in
variation between the two participants appeared to narrow when L2 lexical decision tasks performed after L2 usage, which once again might be evidence of soft-assembly in L2 lexical processing (in that current state is influenced by the immediate experience).

To further investigate the effect of context on response times within individuals, a series of repeated measures of ANOVA were performed on the two participants’ data. The main effect of contexts was found to be significant for both participants, and reaction times were faster when the participant used similar language prior to the lexical decision tasks. Interestingly, while the reaction times for L2 lexical decision tasks were faster when context manipulation in similar language was performed, the same thing did not occur in L1 lexical decision tasks. This result supports the finding in a similar study by Lowie et al. (2014) that the coordination of subsystems were more optimal when a subject became more proficient in L2, whereas the same pattern was not found in L1 that remained stable. The main effect of the contexts revealed in the present study also verified that the coordination of subsystems was affected by participant’s immediate linguistic history. Even more fascinating, when Lowie et al. (2014) found the effect of immediate linguistic history after seven days of immersion, the repeated measures ANOVA showed that even a very immediate, but limited linguistic experience (approximately 10 – 15 minutes) could affect the lexical processing. All in all, the analyses verified the hypothesis that variability in bilingual lexical processing between and within individuals is present. Particularly interesting was the fact that L2 was found to be less stable and more sensitive to context of prior language use as compared to L1.
5.1.4. Pink Noise in Bilingual Lexical Processing

Regarding the fourth hypothesis, self-organizing patterns as manifested in the presence of pink noise are observable both in L1 and L2. PSDE and SDA analyses were applied to investigate the occurrence of a self-organizing pattern. The result from both analyses verified the occurrences of pink noise in both languages regardless prior language use. This can be inferred from the mean of slopes yielded from PSDE, which fell under the range of pink noise ($0 < \alpha < 1$). The occurrences of pink noise within the time series were confirmed to be significant. Thus, it can be established that lexical processing is a self-organizing system as manifested in the presence of pink noise.

The means of spectral slopes and FD across sessions were quite similar. However, a closer examination on FD values calculated from the result of the SDA, which is considered as a more accurate estimation analysis of fractal patterns, showed higher FD mean when participants used similar language with that of presented in the lexical decision tasks, which can be associated with more coordinated patterns. This result was particularly evident in L2, whereas using L1 prior to L1 lexical decision tasks yielded FD that fell slightly under white noise category (FD > 1.5), which indicates random behavior. This result, however, should be interpreted cautiously since ‘whitened’ FD does not always imply the absence of pink noise, since SDA tends to lose its accuracy in characterizing time series that display very strong interdependence, such as pink noise with a spectral slope near -1 (Holden, 2005). Summarizing the result of PSDE and SDA, it can be concluded that pink noise is prevalent in the time series data. In addition, more pronounced pink noise in L2 was found after using similar language before performing...
the tasks. L1 lexical processing, on the other hand, appeared to be unaffected by prior language use.

The result of the current study replicated prior findings concerning the pervasiveness of pink noise in human cognition in general (c.f. Gilden, Thornton, & Mallon, 1995; Kello, Anderson, Holden, & Van Orden, 2008; Van Orden, Holden, & Turvey, 2003, 2005), and bilingual lexical processing in particular (Lowie et al., 2014; Waegenmaekers et al., 2014). As pink noise is considered as a manifestation of metastable patterns of coordination between brain, body and environment (Kello et al., 2008; Wijnants et al., 2000), the presence of pink noise in bilingual lexical processing might be interpreted as a sign of changing coordination between multifarious patterns over time. The significance of the time element in the lexical processing is evident in the significance test. When the order of the data randomized, the fractal patterns also disappeared. Hence, it is reasonable to infer from the finding that each response time is interdependent rather than independent of each other. The interdependence confirms the notion that human cognition works in a continuous rather than discrete manner (Spivey & Dale, 2004). In particular, concerning with bilingual lexical processing, the interdependence also supports the assumption that lexical knowledge and representations are soft-assembled within contexts over time (Caspi, 2010; Larsen-Freeman & Cameron, 2008). To put it differently, given that each response time represents iteration, the current state is influenced by the previous iteration, and becomes an input for the next iteration. Thus, lexical processing can be regarded as a dynamic system, which consists of interconnected elements that change over time.
Furthermore, the prevalence of pink noise in L1 and L2, which indicates self-organization in bilingual lexical processing, runs against component-dominant models that assume lexical representations to behave in passive and discrete manners (c.f. de Bot, 1992; Dijkstra & Van Heuven, 1998; Jackendoff, 2002). On the contrary, the emergence of 1/f noise is an indicator of self-organized criticality (Bak et al., 1987), whereby systems are attracted to self-organize toward optimal equilibrium between over regulated and over random behavior and that provides adaptability to the changing environment. Therefore, regarding lexical processing, SOC implies that lexical items actively self-organize over time, which supports the interaction-dominant hypothesis. Consequently, the discrete component-dominant models are not sufficient to explain the dynamic nature of lexical processing, which is consistent with de Bot's (2004) complexity proposal: “there is no need to develop a specific model for such multilingual processing” (pp. 30). Nevertheless, provided a model for bilingual lexical processing will be developed in the future, the finding of the study suggested that the elements of time and environment in the form of language use should be taken into consideration.

To sum up, the results of the analyses verified the hypothesis that lexical processing in bilinguals is dynamic, and self-organizing, which is manifested in the presence of pink noise in both language. In addition, the analyses also established that the effect of prior language use is more pronounced in L2 rather than L1. This might be explained by the fact that L1 lexical knowledge as well as representation is more stable and coordinated, and thus less sensitive to the environment.
5.2. Conclusion

This study was aimed at investigating whether bilingual lexical processing can be seen as an interaction‐dominant system. In doing so, both linear and non‐linear approaches to time reaction data, which were gathered from a series of lexical decision experiments involving four advanced Indonesian learners of English were applied. Particularly interesting was the use of spectral analyses, whereby the intact order of the time series data were preserved to see the changes of variability pattern over time, which was expected to be more psychologically ecological in capturing the flow of continuous mind occurring in bilingual lexical processing. Being psychologically ecological means stepping away from the computer metaphor for cognition by replacing the concept of discrete representation in mind with “multifarious patterns of neural activation that changes over time” (Spivey, 2004, pp.133). Considering that mind is not a static entity, dynamic changes over time, which is at the heart of DST, should be considered as one of the main features of lexical processing. Hence, in the study focus was given to the variability over time in natural continuous flow of lexical processing by observing intact time series data.

The results of the data analyses confirmed the four hypotheses established in the present study. First, variability was found both in L1 and L2. However, response times in the L2 lexical decision tasks were consistently slower than in L1 lexical decision tasks, which showed more stable behavior in L1. A further analysis on the participants CVs revealed a low between subjects correlation, which indicated that lexical items do not have stable and fixed representations. Lexical representation, therefore, is flexible and
adaptive. Second, very immediate linguistics experience as simulated by performing a series of productive and receptive tasks in particular language was found to have an effect on bilingual lexical processing. The study revealed that prior L2 usage led to a more coordinated behavior of that same language. However, the same result was not found in L1, which showed a random behavior after using similar language, which might indicate that L1 is generally more stable and relatively more independent to prior linguistics experiences than L2. Third, variability was confirmed to be present at between and within individual levels, which showed that human minds do not work in static and homogenous ways as described by the computer metaphor. Interestingly, the data analysis suggested that even a very short immediate linguistic experience (approximately 10 – 15 minutes) affected lexical processing, with a more pronounced effect found in the L2. Finally, pink noise was prevalent in the data with a more pronounced pink noise found in L2 after using similar language before performing the tasks. L1 lexical processing, on the other hand, appeared to be unaffected by prior language use. This confirmed the fourth hypothesis that lexical processing in bilingual is expected to be dynamic, and self-organizing, which is manifested in the presence of pink noise in both languages. In addition, prior language use affects lexical processing with pronounced effect in as L1 lexical knowledge and representation are more stable and coordinated, and thus less sensitive to the environment.

However, keeping in mind that the study only involved a limited number of participants, any inferences should be made cautiously. Any conclusion drawn from the result, then, might not be generalizable. Nevertheless, the results of the study provide
clear evidence that variability does not only occur between subjects, but also within subjects. The emergence of variability at various scales and levels might be a proof that language processing exhibits fractal patterns. In addition, the lexical decision experiment design which required participants to do semantic processing by categorizing certain items into living or non-living things was prone to processing problems, such as the ambiguous categorization of particular words (e.g. parts of the body). Consequently, longer reaction time on certain words might not only reflect lexical processing, but also other cognitive processes.

In the future studies, several directions could be taken. First, a more detailed effect of individual differences, such as level of proficiency and age of onset could be explored. Second, the current study was only a very modest attempt to gather and approach data in a more continuous and ecologically valid procedure, such as by taking a longitudinal method in longer time scale to better examine the development trajectory of the process. It is also interesting to see how changes within in individual might affect the changes in interaction between individual, such as in the case of scaffolding in classroom interaction. A further investigation on how novice and proficient L2 learners interact, and how the variability pattern shows coadaptation between the individuals might not only be interesting but also useful to shed a light on the dynamics of L2 learning. Finally, although spectral analyses applied in the present study were deemed powerful to look at relations between items over the whole experiments rather than isolated items, the PSDE and SDA methods chosen in the study tend to lose some of their accuracy with high frequency data which appeared to be ‘whitened’. Future studies, then, might apply other
non-linear to gauge fractal patterns in time series data. Several alternatives, to name a few, might include applying ARFIMA modeling, sample entropy, and Recurrence Quantification Analysis.

Finally, the contribution of this study has been to confirm that bilingual lexical processing is an interaction-dominant process whereby lexical representations are flexible rather than static. The finding implies the need to revisit modular approach that views that language processing occurs in discrete manners which disregard time and environment aspects. Therefore, provided a model for bilingual lexical processing will be developed in the future, the finding of the study suggested that the elements of time and environment in the form of language use should be taken into consideration. Finally, this study highlighted the fact that lexical processing in bilingual minds does not work in a modular computer metaphor. Instead, in line with Spivey & Dale (2004) who proposed that human cognition is always on continuous flow, it can be proposed that lexical processing is analogous to a flowing river, whereby the current of the flow dynamically interact with various factors, such as the contour of the landscape, types of surrounding soils, weather, and even organisms living inside it. In addition, although almost all rivers flow to the ocean, each has a distinctive trajectory and creates unique meanders along the path over time, which is similar to bilingual minds.
References


FINDING HARMONY IN CHAOS


Lorenz, E. (1972). Does the flap of a butterfly’s wings in Brazil set off a tornado in Texas?


### Appendix A: Word List for Lexical Decision Task

#### L.1: Bahasa Indonesia

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mulut  embun  seragam  pramuwisma
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<td>Burner</td>
<td>Pond</td>
<td>Courthouse</td>
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<td>Sail</td>
<td>Rug</td>
<td>Catfish</td>
<td>House maid</td>
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<td>Farm</td>
<td>Stepmother</td>
<td>Bathroom</td>
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<td>Pine</td>
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<td>Stove</td>
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<td>Shorts</td>
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<td>Paper</td>
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<td>Incense</td>
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<td>Wheelchair</td>
<td>Window</td>
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<tr>
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<td>Handbag</td>
<td>Basket</td>
<td>Shack</td>
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Context 1: Bahasa Indonesia for English lexical decision task
Tugas 1 : Teks Rumpang
Beralih ke aksi pemerintahan Jokowi-JK. Gebrakan ______ menyelamakan sektor ______ di tanah ______ tidak main-main-. ___ kapal yang ______ di laut ______ didedakkan, dan ___ ditenggelamkan.

Sebetulnya ______ ini, penenggelaman _____ ini, juga ______ dilakukan di ________
Susilo Bambang ________ saudara. Selama ______ Yudhoyono memerintah___ 38 kapal
ditenggelamkan.

Dua ______ yang ditangkap ___ Abdul Halim ______ Kusuma komando ______ timur Indonesia
14 Desember _____ di laut ______ Maluku ini _______ serta ditenggelamkan. ___
kapel ini ____________ bernama KIA _______ 4 dan ___ Senturi 7 ______ kapasitas muatan
_hingga 250______ ton. Pengadilan ______ Ambon memvonis _____ kapal ini ______
menangkap ikan __ laut Arafura ______ surat izin ___________. Sementara awak _____ masih
ditahan __ Lantamal 9 ______ untuk menunggu _____ hukum.

"__ dua dulu. ___ dulu. Ini ______ bukti bahwa __________ tegas. Kita _____ untuk
memberantas ______ fishing. Kita _____ bahwa ini - kedua kapal ___ menangkap ikan __ laut
Arafuru ___ dokumen apapun ___ pemerintah Indonesia. ____ dengan segera ____ bakar.
Kita ____________. Untuk yang ________, lengkapi izin. ___ saja. Kalau _____ akan kita
_____. Kita tenggelamkan."

____ menangkap 8 ______ pencuri ikan ___ sepekan lalu. ___ sudah ditenggelamkan. ___
kapel lainnya _____ menunggu proses ____________, dan jika ________ mencuri penenggelaman
____ akan diberlakukan.

Peledakan dan ____________ kapal ini ________ langkah tegas ____ pemerintahan Jokowi-JK
____ menitikberatkan sektor __________. Pemerintahan Jokowi ____ resmi memerintah ____
Oktober lalu, _____ sebenarnya sudah __ kapal yang _____________ karena mencuri ___ di
perairan ___________. Sebelumnya pemerintahan Susilo Bambang Yudhoyono ___ menerapkan
kebijakan __. Dari tahun ___ sampai tahun _____ pemerintahan SBY _____ menenggelamkan
38 ______.

Sebagai ______ maritim, Indonesia ________ lautan yang sangat ____. Sudah sepatutnya
______ yang memerintah _____ menjaga wilayah ____ Indonesia agar _____ dirampas
kekayaannya ____ negara lain. Tim liputan Kompas.
FINDING HARMONY IN CHAOS 82

Tugas 2: Pertanyaan Pemahaman
Jawablah pertanyaan-pertanyaan berikut berdasarkan teks yang telah Anda dengarkan!
1. Apa gagasan utama dari berita tersebut?
2. Mengapa pemerintah menenggelamkan kedua kapal tersebut?
3. Pesan apakah yang hendak disampaikan oleh pemerintah lewat penenggelaman kapal tersebut?
4. Apa yang harus dilakukan pemilik kapal bila ingin menangkap kapal di wilayah perairan Indonesia?
5. Berapakah jumlah kapal yang telah ditenggelamkan sejak tahun 2007 hingga saat berita tersebut diturunkan?

Tugas 3: Tugas Produktif.
Ceritakan kembali pokok pikiran berita yang telah Anda dengarkan.

Transkrip
Beralih ke aksi pemerintahan Jokowi-JK. Gebrakan pemerintah menyelamatkan sektor perikanan di tanah air tidak main-main. Dua kapal yang ditangkap di laut Arafura diledakkan, dan juga ditenggelamkan.

Sebetulnya kebijakan ini, penenggelaman kapal ini, juga pernah dilakukan di pemerintahan Susilo Bambang Yudhoyono saudara. Selama presiden Yudhoyono memerintah ada 38 kapal yang ditenggelamkan.


Kormatim menangkap 8 kapal pencuri ikan pada sepekan lalu. Dua sudah ditenggelamkan. Enam kapal lainnya masih menunggu proses persidangan, dan jika terbukti mencuri penenggelaman juga akan diberlakukan.


Sebagai negara maritim, Indonesia memiliki lautan yang sangat luas. Sudah sepatutnya siapapun yang memerintah harus menjaga wilayah laut Indonesia agar tidak dirampas kekayaannya oleh negara lain. Tim liputan Kompas TV.
Tugas 1: Teks Rumpang

Sebagian orang masyarakat beranggapan bahwa ternyata berkebun itu sangat sulit untuk dilakukan. Benar atau _____ ya? Terutama _____ mereka yang _____ di perkotaan. _____ bagaimana cara __________ pekarangan rumah _____ sempit menjadi _____ buah dan _____ sayur?

_____ memiliki kebun _____ di pekarangan _____? Metode tanam __________ solusinya. Hemat _____, hemat tenaga, _____ hasilnya memuaskan. _____ yang dirasakan ____ Lasti Apriyani ________. Warga Bandung ___ menyulap pekarangan ______ menjadi kebun __________ penghasil selada, __________, bayam, paprika, _____ hingga melon.

Sesuai namanya, _____ ini mengandalkan ___ sebagai media _____. Jadi tak _____ cara konvensional _____ membutuhkan tanah __ pupuk. Hasilnya ______ dengan sejumlah __________. Salah satunya _____ dari unsur _____ seperti logam.

“Semua tanaman __________ bisa dihidroponik. _____ kan kita _______ pilih yang ______ ekonomisnya masuk. _____ mau tanaman ________ yang keras _____ seperti tanaman _______ seperti mangga __________ bisa, tapi ___ tidak mungkin ____ musti nunggu ______ tahun. Kita _____ kasih nutrisi ________ sambil nunggu ___ berbuah. Makanya _____ pilih tanaman-tanaman _______ sayuran, atau _______ buah seperti ____ yang cuma _______ bulan umurnya. _____ nggak perlu _____ yang subur. ____ mau bertanam __ beton pun _____. Jadi kita ____ bertanam di ____ rumah pun ____. Di balkon ___. Jadi. Dan _____ juga nggak __________ musim ya. ____ tanam apa ____, karena kita ____________ dengan nutrisinya.”

_______ tanam dengan ______ hidroponik telah ______ Eva sejak ___ tahun lalu._______ dengan komunitas _______ bareng hidroponik, _____ ia sering _________ pelatihan. Berbagi ___ bersama sesama _______ tanaman di _______ kota: mulai ___ Jakarta, Medan, ________, hingga Balikpapan. ___ hanya itu, __________ juga membuka _________ bisnis yang _____ menjanjikan. Yakni _____ menjual berbagai _________ bertanam hidroponik ______ online.

“_______ aja sih _________ udah. Kemarin _____ sempat ke _________ udah sempat. _____ ya sekitaran _________ udah pasti. __________. Di sini ____ ada reseller-reseller _____ dari Kalimantan, ____ Sulawesi. Ada ____.”


Tugas 2: Pertanyaan Pemahaman
Jawablah pertanyaan-pertanyaan berikut berdasarkan teks yang telah Anda dengarkan!
1. Apa tema utama teks berita yang Anda dengarkan?
2. Mengapa metode hidroponik dapat menjadi solusi untuk bercocok tanam di perkotaan?
3. Apa kelebihan metode hidroponik dibanding cara konvensional?
4. Mengapa tanaman sayur lebih banyak digunakan untuk metode hidroponik?
5. Bagaimanakah meode hidroponik dapat membuka peluang usaha?

Tugas 3: Tugas Produktif.
Ceritakan kembali pokok pikiran berita yang telah Anda dengarkan.

Transkrip

Sebagian orang masyarakat beranggapan bahwa ternyata berkebun itu sangat sulit untuk dilakukan. Benar atau tidak ya? Terutama bagi mereka yang tinggal di perkotaan. Lalu bagaimana cara memanfaatkan pekarangan rumah yang sempit menjadi kebun buah dan juga sayur?


Sesuai namanya, metode ini mengandalkan air sebagai media tanam. Jadi tak seperti cara konvensional yang membutuhkan tanah dan pupuk.


Context 3: English for Bahasa Indonesia lexical decision task

Context Manipulation

L2 English

Task 1: Receptive tasks: Listening

Instruction:
In this task, you are going to listen to an audio text for three times.
For the first listening, your task is simply listening to the text.
Next, for the second listening, you are going to fill in the gaps while listening to the audio text.
Finally, for the third listening, you can listen to the audio text to check your answer.

Manipulation 1: Cloze test.
It's time to learn about one of the constellations in the night sky. Do ___ recognize this __________? It's Orion! ___ visible from _____ to March, _____ is one __ the easiest __________ to find __ the sky. _____ is also ______ the Hunter, _______ in Greek __________, Orion was _ giant hunter. ___, while he ___ hunting, he _______ that he ___ kill every _____ on earth. ______ Earth did ___ like this ___ at all, ___ so she ___ a giant _______ to kill ___. After he ___ dead, Zeus, ___ king of ___ gods, placed _____ in the _____ sky. Zeus ___ the scorpion ___ the sky, __ well, and ___ the scorpion _____ Orion around ___ heavens forever. ____ is why _____ is in ___ sky in ______: in summer ___ scorpion comes ___ chases him ___. Orion's belt ___ fun to ___ if you’re ________ from your ___________, but astronomers ___ more interested ___ what's below __ - Orion's _______. In the _______. Orion's sword ___ a magical ____, but ___ the help __ modern telescopes, ___ can see ___ makes it ___ so bright. ______ sword is ___ to the _____ orion nebula, _ cloud of ___, hydrogen, helium, ___ other gases. ___ orion nebula ___ a special ____ of nebula _____ a stellar _______. At least _____ hundred stars ___ currently being _____ there. If ___ sky is ____ enough, you ___ see the _____ with just ___ eyes, but you ___ get a _____ look with ___________ or a __________. Next time ___ are out ___ night and ___ sky is ___ of stars, ___ a look! And see if you can find Orion, the constellation of the hunter.

Task 2: Comprehension

Instruction:
In this session, you are going to listen to the audio text once, to answer the following questions orally. You may take notes while listening to the text.

1. What is the text about?
2. When is Orion particularly most visible?
3. According Greek mythology, why did Mother Earth send Scorpion to kill Orion?
4. What is Orion Nebula?
5. Why is Orion Nebula called a star nursery?

Task 3: Productive Task (1 item)

Please retell the greek mythology version of the origin of Orion constellation.
Transcript:

It's time to learn about one of the constellations in the night sky. Do you recognize this constellation? It's Orion! Most visible from January to March, Orion is one of the easiest constellations to find in the sky. Orion is also called the Hunter, because in Greek mythology, Orion was a giant hunter. Once, while he was hunting, he bragged that he could kill every animal on earth. Mother Earth did not like this plan at all, and so she sent a giant scorpion to kill Orion. After he was dead, Zeus, the king of the gods, placed Orion in the night sky. Zeus sent the scorpion into the sky, as well, and now the scorpion chases Orion around the heavens forever. That is why Orion is in the sky in winter: in summer the scorpion comes and chases him away. Orion's belt is fun to find if you're stargazing from your backyard, but astronomers are more interested in what's below it - Orion's sword. In the story, Orion's sword has a magical glow, but with the help of modern telescopes, we can see what makes it look so bright. Orion's sword is home to the great Orion nebula, a cloud of dust, hydrogen, helium, and other gases. The Orion nebula is a special kind of nebula called a stellar nursery. At least seven hundred stars are currently being formed there. If the sky is dark enough, you can see the nebula with just your eyes – but you can get a better look with binoculars or a telescope. Next time you are out at night and the sky is full of stars, take a look! And see if you can find Orion, the constellation of the hunter.

Reference:
FINDING HARMONY IN CHAOS

Context 4: English for English lexical decision task
Context Manipulation
L2 English
Task 1: Receptive tasks: Listening
Instruction:
In this task, you are going to listen to an audio text for three times.
For the first listening, your task is simply listening to the text.
Next, for the second listening, you are going to fill in the gaps while listening to the audio text.
Finally, for the third listening, you can listen to the audio text to check your answer.
Manipulation 1: Cloze test.
Since the dawn of time the stick has been essential to human survival: helping us explore the world, and protect ourselves. ___ never before ___ the course ___ human history ___ we seen ___ sticks perhaps ______ contribution to ___________. It is _________ the anatomically ______, extending ___ to take ______ photos of _______ and the ______ behind us.

O yes. ___ are talking _____ the selfie ______. Now I ___ what youre _______. People are ______ around the ______ with their____ on poles. _ thought the___ thing, but ____ with me ___ for a _______. There are ______ some real ______ of using ___ of these: ___ dont have ___ ask a________ to hold___ phone; you ___ capture better ___ angle of ________; and you ___ record more ______ video. Ive ______ if I ___ going to ___ this absurd _______ trend, I ______ have the ___ one.

That's____. Not all ______ sticks are_______ equal, which ___ why I've ___ testing fourteen ___ them. Sure, ______ a selfie ___ is just _ pole with ___ attachment for ____ phone at ___ end. But ___ one, under ______ dollars, lets ___ take a _______ with just _ press of _ button right __ the pole. Attach your______ to the ___ of forty ___ TV antenna _______ pole, plug ___ cord into ___ headphone jack, ___ get shooting. ___ companies sell ___ exact same ______ made stick. ___ one I ______ called LookDG _____ twenty dollars ___ Amazon.

Riverental ____ this one ___ 15 dollars, ___ instead of ___ headphone thing, ___ gives you ____ small little _______ remote. Its ___ more comfortable ___ hold than ___ others, but ___ keeps using ___ little thing. ___ why the________ dollar pick ___ has Bluetooth ___ right in. ___ works well, ______ you have ___ remember to _____ your stick, ___ it can ___ wet. All ___ sub thirty ______ options have ___ thing in ______: they feel ______ cheap, especially ___ part that _______ to your_____. If someone ______ hated your_______ stick, they ______ break it ___ over their ___.

If ___ want something ___ durable or ________, you need ___ pay more ______. I like ___ sixty dollars ______ extreme, sometimes ___ the Ultra ___ Xpert, and ___ comfortable grip ___ the best ___ of all ___ them. There's ___ shutter gimmick ___ in. You ___ to use ___ timer or ___ a five ______ blue tooth ______, but it's ______ and worked _____ when I ___ into Neil Young.

Selfie____ aren't just ___ family photos ___ beauty shots, ___ also really ___ off when ___ pro sticks ___ action shots. I highly recommend _____ own seventy ______ three way. ___ can change ______ and even ______ it into ___ tripod. I ___ like the ___ hundred dollar ______ pole. This ___ the tesla ___ selfie stick, ___ it has ___ in battery ___ recharges phones ___ Go Pros. ___ that forty _____ dollars QuickPod Extreme you can ___ with the _____ amount is ______.
Now, I____ want to ____ to you. __ matter which ___ of these ___ go with, _____ still going __ look pretty __________ with your _____ on a ______. But if _____ okay with ____, and _ am, I’d __ with the LookDG on the _____ and the QuickPod Selfie Extreme.

Well you could go back and do what our ancestors did: find your stick, make your own.

Task 2: Comprehension

Instruction:
In this session, you are going to listen to the audio text once, to answer the following questions orally. You may take some notes while listening to the text.
1. What is the text about?
2. Why has sticks been essential for human survival?
3. How can we benefit from using a selfie-stick?
4. How is under thirty dollar selfie sticks similar to each other?
5. Which selfie sticks does the writer recommend?

Task 3: Productive Task (1 item)
Tell your opinion about the selfie phenomenon.
- What do you think about people taking selfie?
- Why do you think they take selfie pictures?
- Have you ever taken a selfie picture of yourself? Do you enjoy it? Why/Why not?

Transcript
Since the dawn of time the stick has been essential to human survival: helping us explore the world, and protect ourselves. But never before in the course of human history have we seen the stick’s perhaps greatest contribution to civilization. It is enabling the anatomically impossible, extending arms to take better photos of ourselves and the sight behind us.

O yes. We are talking about the selfie stick. Now I know what you're thinking. People are walking around the streets with their phones on poles. I thought the same thing, but stick with me here for a second. There are actually some real advantages of using one of these: you don’t have to ask a stranger to hold your phone; you can capture better wider angle of yourself; and you can record more stable video. I’ve figured if I am going to join this absurd looking trend, I should have the best one.

That's right. Not all selfie sticks are created equal, which is why I've been testing fourteen of them. Sure, fundamentally a selfie stick is just a pole with an attachment for your phone at the end. But this one, under twenty dollars, lets you take a picture with just a press of a button right on the pole. Attach your phone to the top of forty inch TV antenna looking pole, plug the cord into the headphone jack, and get shooting. Many companies sell the exact same Chinese made stick. The one I tested called LookDG costs twenty dollars on Amazon. Rivertal sells this one for 15 dollars, and instead of that heaphone thing, it gives you this small little Bluetooth r. It’s much more comfortable to hold than the others, but it keeps using this little thing. That’s why the twenty-five dollar pick stick has bluetooth bulit right in. It works well, though you have to remember to charge your stick, and it can get wet. All these sub thirty dollars options have one
thing in common: they feel really cheap, especially the part that clasps to your phone. If someone really hated your selfie stick, they could break it right over their knee.

If you want something more durable or waterproof, you need to pay more though. I like the sixty dollars selfie extreme, sometimes called the Ultra or Xpert, and its comfortable grip is the best out of all of them. There’s no shutter gimmick built in. You have to use a timer or buy a five dollar blue tooth remote, but it’s sturdy and worked great when I run into Neil Young.

Selfie sticks aren’t just for family photos and beauty shots, they also really took off when go pro sticks for action shots. I highly reccomend Go-Pro own seventy dollars three way. You can change angles and even turns it into a tripot. I also like the one hundred dollar power pole. This is the tesla of selfie stick, and it has built in battery that recharges phones or Go Pros. But that forty eight dollars QuickPod which you can get with the GoPro ammount is lighter.

Now, I don’t want to lie to you. No matter which one of these you go with, you’re still going to look pretty ridiculous with your phone on a stick. Bbut if you’re okay with that, and I am, I’d go with the LookDG on the cheap and the QuickPod Selfie Extreme.

Well you could go back and do what our ancestors did: find your stick, make your own.
Appendix C : L2 C-Test

Instruction:
The test consists of 3 texts whereby every second word is missing half of its letters. If a word has an uneven number of letters, then half + 1 of the letters are missing. You have to complete the words. For example:
Many volun____ from Ar__ countries h__ gone t__ Afghanistan dur___the 1980s.
Th____ wanted t____ help t____ Afghans fi____ the inva____ Russian ar____.

Many volunteer from Arab countries had gone to Afghanistan during the 1980s. They wanted to help the Afghans fight the invading Russian army.

Text 1: Intelligence
Defining intelligence is highly problematic. Is th_________ an intell_________ that ena________ us t_________ solve a_________ kinds o_________ problems a_________ answer a_________ questions, regar_________ of th_________ nature? O_________ are th_________ different intell_________ that he_________ us de_________ with part_________ problems a_________ solutions? Ma_________ people sug_________ that th_________ is n_________ one ki_________ of intell_________ , but a_________ least ei_________ different types, including verbal, spatial and emotional intelligence. The scientific community is divided on the issue.

Text 2: Solar eclipses
Solar eclipses happen when the Moon blocks light from the Sun. The earth darkens and stars appear in the sky as if it is night. During t_________ eclipse, y_________ can s_________ details i_________ the ou_________ part o_________ the s_________ which y_________ cannot usu_________ see. Y_________ should ne_________ look a_________ a solar ecl_________ directly bec_________ it c_________ damage yo_________ eyes. B_________ you c_________ wear spe_________ glasses th_________ let y_________ see i_________ but ke_________ your ey_________ protected. I_________ ancient tim_________ people we_________ frightened b_________ solar ecl_________ because th_________ did n_________ understand th_________. But now we understand how they happen and know they are amazing to watch.

Text 3: Gospel Singer
Mahalia Jackson (1911-72), was an American gospel singer. Born in New Orleans, she sang in church choirs during her childhood. Moving (1927) t_________ Chicago, s_________ worked a_________ various men_________ jobs a_________ sang i_________ churches, a_________ at rev_________ meetings, attra_________ attention f_________ her vigo_________ , joyful gos_________ style. A_________ her reput_________ grew s_________ made nume_________ recordings, a_________ she gai_________ national recog_________ with h_________ Carnegie Hall de_________ in 1950. Deeply committed to the civil- rights movement, she was closely associated with the work of Dr. Martin Luther King.
Appendix D: Power Spectrum Density Estimation Result

Participant 1
Session 1

Session 2
Participant 2
Session 1

Session 2
Session 3

Session 4
Participant 3
Session 1

Participant 3
Session 2
Participant 4
Session 1

Session 2
Session 3

Session 4
Appendix E: Standardized Dispersion Analysis Result

Participant 1

Session 1

Session 2

Session 3

Session 4
Participant 2

Session 1

Session 2

Session 3

Session 4
Participant 3

Session 1

Session 2

Session 3

Session 4
Participant 4

Session 1

Session 2

Session 3

Session 4