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# Application of The Dual-Route Model in Exploring Dyslexia and Dysgraphia in Arabic Speaking Adults With Aphasia: Clinical and Theoretical Implications

Maha Aldera
maha_slp@hotmail.com

# Application of The Dual-Route Model in Exploring Dyslexia and Dysgraphia in Arabic Speaking Adults With Aphasia: Clinical and Theoretical Implications

by

Maha Aldera

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Signature sheet

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Doctoral Candidate, **Maha A. Aldera**, has successfully defended and made the required modifications to the text of the doctoral dissertation for the **Ph.D.** during this **Spring Semester 2017**.

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Committee Member:
Dr. Genevieve Pinto Zipp ____________ Date 4/19/17

Committee Member:
Dr. Nadine Martin ____________ Date 4/18/2017

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## ABSTRACT

**Objective:** The cognitive neuropsychology is based on the “universality” assumption, which suggest that all normal people have the same cognitive systems regardless of their culture and language (Coltheart, 2001). The aim of the study is to test the universality assumption of the dual-route model (DRM) for spelling and reading in modern Arabic language. The study follow the same architecture of the DRM taking into considerations specific variables that hold certain features of the Arabic script.

**Methods:** The study results were secured by using case series method analysis of each individual participant’s performance. The Case series method offered the ability to look into each individual’s symptoms and error types and also took into account individual variances. The profiles of fifteen adults with left-hemisphere strokes were investigated by analyzing their performance in writing to dictation and reading aloud tasks of words and non-words, and discuss the profiles of acquired dysgraphia and dyslexia in these individuals. **Results:** The patterns of impairment observed in each patient were discussed based on the dual-route model of spelling and reading aloud. The results yield different types of dysgraphia and dyslexia but no evidence of surface dysgraphia or surface dyslexia. The types of spelling impairments were graphemic buffer dysgraphia (46%), followed by mixed dysgraphia (27%) and lastly phonological dysgraphia (20%). Reading aloud impairment, on the other hand, showed a majority of deep dyslexia (46%), followed by phonological dyslexia (20%), mixed dyslexia (14%), and a much lower incidence of letter-by-letter dyslexia (6%). **Conclusion:** All of the components hypothesized by DRM were impaired to some degree in each participant.

These components are cognitive functions that in Arabic skilled reader, comprise a highly practiced mechanism specialized for spelling and reading aloud. Elements of these components, such as the sub-lexical route may be involved differently and that the relative impact of both routes varies substantially. The evidence from reading and writing disorders in other languages, as reported in this study, contribute to the theoretical understanding of the cognitive models with the focus on the unique orthographic differences that serve as a basis for hypothesizing about breakdowns within a language.

*Keywords*: Dual-route model, cognitive neuropsychology, dysgraphia, dyslexia, Arabic orthography, aphasia

## Chapter I

## INTRODUCTION

### General Background

After a stroke, many people face communication challenges due to impaired language function (i.e. Aphasia), which is frequently present with combined reading and spelling impairments known as “acquired dyslexia and acquired dysgraphia”. The preliminary notion of classifying acquired dyslexia and dysgraphia was based on the localization theory that attempts to classify different aspects of behavior by major characteristics and then link these characteristics to areas of the brain in which the damage has occurred using clinic-pathological correlation.

In the early 1970s, the localization notion was replaced with the rise of the cognitive neuropsychology (CN) model that focused on the cognitive components involved in processing information and the interconnections between these components. One of the prominent CN models that has been extensively studied and reported in the literature is the Dual-route model (DRM) for reading and spelling (Coltheart, 1981,9985; Caramazza, 1988; Coltheart & Rastle, 1994; Coltheart, Rastle, Perry, Langdon, & Ziegle, 2001; Houghton & Zorzi, 2003). Using the DRM, different types of acquired dyslexia and dysgraphia have been reported in English language. However, the literature suggested that different orthographies might be processed differently (Weekes, 2005,2012) and this claim needs to be verified in other languages such as Modern Arabic. Thus, this study examines the application of the dual-route model in exploring dyslexia and dysgraphia in Arabic speaking adults with aphasia.

## Models and Methods of Investigation

The origins of CN arose in two studies of people with reading disorders by Marshall and Newcombe (1966, 1973), and the CN approach that was developed from an initial focus on reading disorders now includes a variety of other cognitive domains. Morton (1969), through the single-word processing logogen model, introduced the first visual illustration of a CN model, which showed the functions of various mental operations to perform tasks such as spoken word and reading. The initial model was revised and was re-proposed later by Patterson and Shewell in 1987, as shown in Figure 1.

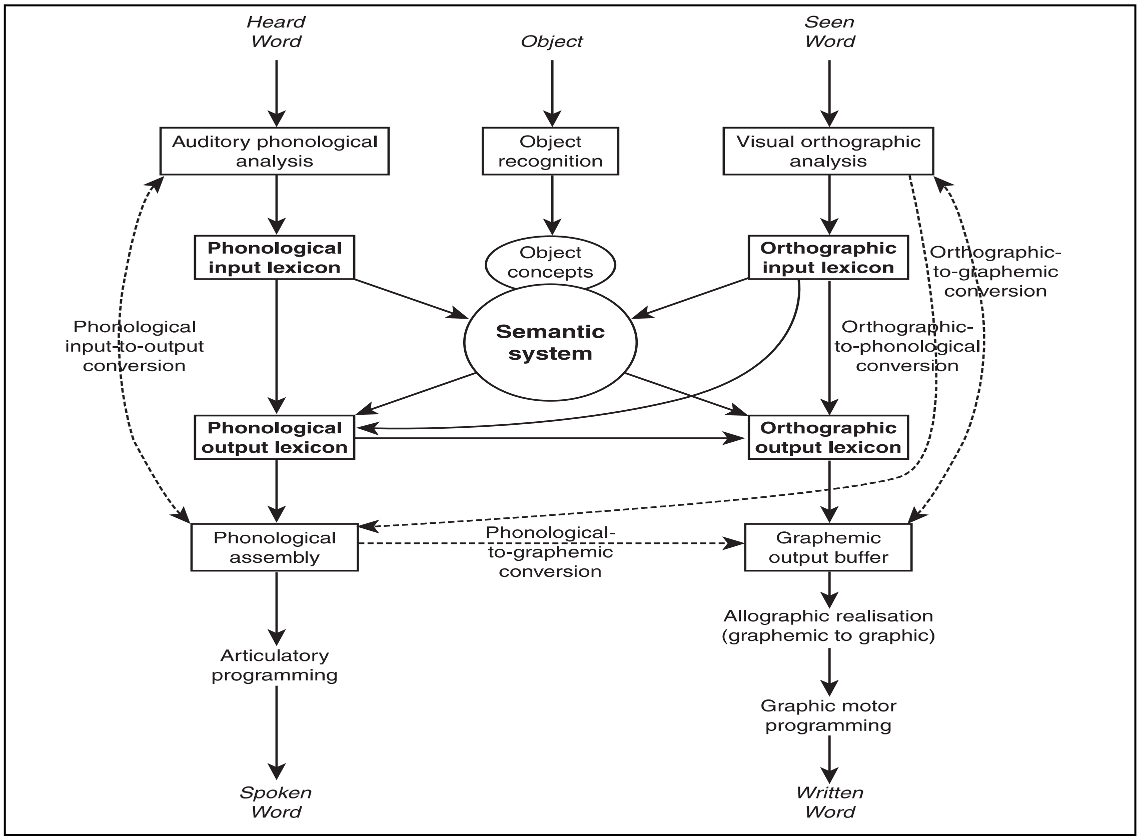


*Figure 1.* . Language-processing model based on Patterson and Shewell's (1987).

This revised CN model provides a means of visualizing the stages involved in typical language tasks, such as producing and understanding single words. It provides a theoretical framework in which the abilities of individuals with aphasia (IWA) can be investigated, and enables therapists to formulate hypotheses about which processing mechanisms are impaired. These in turn help the therapist to determine and design patient centered plans of care. The complexity of the CN model (as seen in Figure 1) has been broken down into simple and manageable models, where each model represents a domain of investigation and allows one to view each part of the language system independently such as reading or spelling (Coltheart, Rastle, Perry, Langdon, & Ziegle, 2001; Whitworth, Webster, & Howard, 2005).

The CN models were initially investigated using single case study methods, and from these studies three essential features were evident: (1) the performance of the individual, not the average of a group, is the important evidence; (2) the nature of errors is informative; and (3) explanations of individuals' performances are to be couched in terms of information processing models of normal language processing and not in terms of brain lesions (Whitworth, Webster, & Howard, 2005).

More recently, methods have shown a gradual change. While the early studies used in-depth investigations of single and multiple individuals, most recently there has been an increasing use of case series designs where a series of people are investigated using the same set of tasks (Nickels, Howard, & Best, 2011; Olson & Romani, 2011). According to Schwartz and Dell (2010), a case series study has the following characteristics: (1) there is no control group and data from the sample are not aggregated, (2) the target event is modeled in relation to patients, time treatment variables using regression techniques, (3) the goal of the analysis is to understand the cognitive mechanisms responsible for the covariance and this involves developing and testing a statistical or processing model, (4) the sample number is 10 or more, (5) it preserves and uses individual data by characterizing the distribution of scores and what factors covary with the scores, (6) it tests a set of individuals on a common set of measures and analyzes the data per individual and as a group, (7) it identifies theoretically important quantitative trends in the sample, and (8) it explains the variation in the primary measures taken from the patients' sample in order to draw inferences about cognitive functions.

## Theoretical Framework and Cognitive Architecture of Reading and Writing

The CN model for reading and spelling that has been frequently studied and reported in the literature is the Dual-route model (DRM) (Coltheart, Rastle, Perry, Langdon, & Ziegle, 2001). The reading and spelling processes in this model, as shown in Figure 2 and 3, are subdivided into two components: central and peripheral. The central process in the DRM suggests three independent reading and spelling processes: lexical processes, sub-lexical processes, and post-lexical processes (Rapp, 2002).

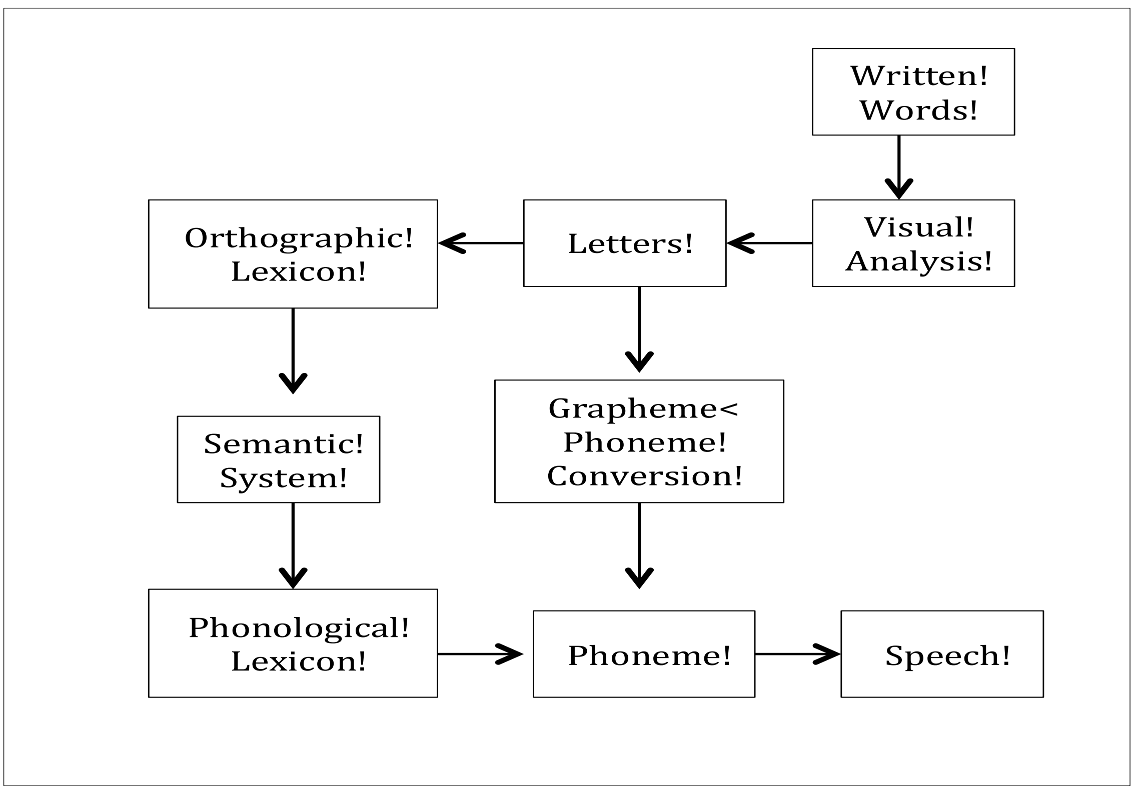


*Figure 2.* The Dual-Route Model (DRM) for reading aloud (adopted from Coltheart et al., 2001; Hillis, 2002).

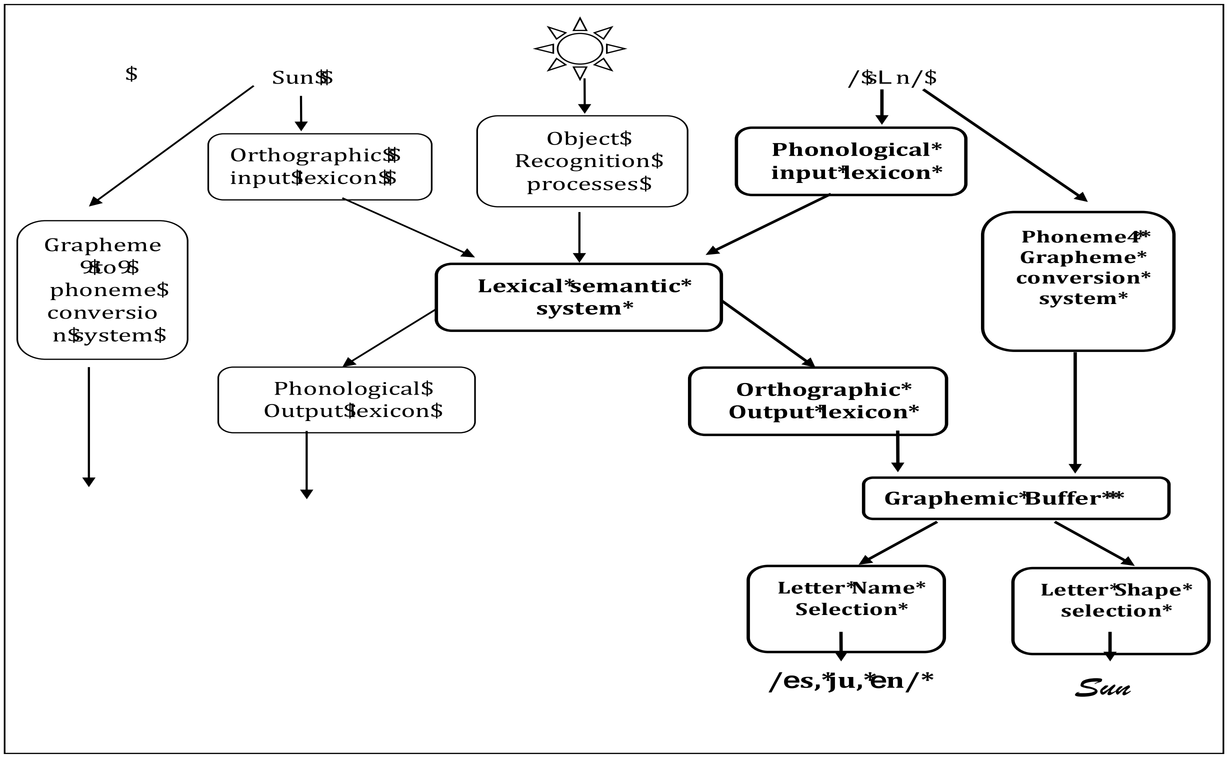


*Figure 3.* The Dual-Route Model (DRM) for spelling (bolded) (Rapp, 2002).

According to Rapcsak and Beeson (2000), processing written language in these models is accomplished by two distinct but interactive lexical and non-lexical routes. Reading and spelling by the lexical route rely on the activation of word-specific orthographic and phonological memory representations. The lexical route processes all familiar words, regardless of whether they are regular or irregular in terms of their letter–sound relationships. However, this route fails to process unfamiliar words or non-words, as these words do not have lexical representations. In contrast, the non-lexical route utilizes the sound-spelling correspondence rules. The non-lexical route processes non-words (e.g., plunt) and also regular words that strictly obey English phoneme–grapheme conversion rules (e.g., must). However, the non-lexical route cannot produce a correct response to irregular words that violate these rules (e.g., choir). Attempts to read or spell irregular words by the non-lexical route result in regularization errors (e.g., “have” is read to rhyme with “save”, or “tomb” is spelled as “toom”) (Rapcsak, & Beeson, 2000).

The post-lexical processes consist of a working memory system (response/ graphemic buffer) that remains active and available throughout the process to execute the appropriate motor actions. The buffer process is strategically located in the reading and spelling systems and it mediates between processes needed to generate graphemic or phonemic representations for the items and the more peripheral processes needed for motor output (Carammazza et al., 1987).  It receives all types of verbal stimuli (words, nonwords), either from the lexical or the non-lexical routes, and keeps the representations active and available throughout the process to execute motor actions (Rapp, 2002). Caramazza et al. (1987) proposed a set of characteristics for identifying selective damage to the Graphemic Buffer including: (1) A similar pattern of errors for nonwords and familiar words, (2) no effect of lexical factors such as word frequency, imageability, grammatical word class or concreteness, (3) increased errors with word length, (4) error types such as substitution, deletion, transposition or insertion of individual letters, and (5) influence of letter position or what is referred to as “bow-shaped” function, that is a higher incidence errors in the medial letter position. The role of orthographic working memory and how this post-lexical component behaves in reading aloud and spelling is debated. Most studies have focused on the role of GB in spelling, but few studies focused on the GB role in reading (Caramazza, Capasso, & Miceli, 1996, Tainturier & Rapp, 2003).

**Impairments to the Central Process of the DRM**

The theoretical structure of the DRM, derived from case studies, was able to explain the clinical pathological findings seen in acquired dysgraphia and dyslexia. Any of the modules in the DRM can be lost or damaged as a result of cortical lesions, and the value of the DRM of reading and spelling was judged by the ability to account for patterns of abnormal performance observed in clinical settings. As a result, several types of central reading and spelling impairments in English language were distinguished and explained by the DRM.

For instance, acquired surface dyslexia in English refers to a selective impairment of the ability to read aloud irregularly spelled words with preserved ability to read regularly spelled words and non-words (Beauvois, & Derousne, 1981; Goodman-Schulman & Caramazza, 1987; Romani, Ward, & Olson, 1999). Acquired surface dysgraphia is characterized by impaired spelling of irregular words e.g. yacht and homophone confusions in writing. The opposite pattern of reading impairment is acquired phonological dyslexia, which refers to impaired reading of nonwords together with a preserved ability to read irregular and regular words (Shallice, 1981; Ogden, 1996). Phonological dysgraphia refers to poor spelling of nonwords accompanied by preserved spelling of irregular and regular words. Deep dyslexia and deep dysgraphia are similar to phonological dyslexia and dysgraphia except that patients produce semantic errors in reading and writing (Bub, & Kertesz, 1982; Cipolotti, Bird, Glasspool, & Shallice, 2004; Hillis, Rapp, & Caramazza, 1999).

Finally, there is the orthographic working memory impairment, also known as graphemic buffer dysgraphia. This is a selective impairment at the graphemic output buffer that causes letter substitutions, additions and omissions in both words and in nonwords and is highly affected by word length (Caramazza et al., 1987; Caramazza & Miceli, 1990; Miceli & Capasso, 2006). In reading aloud, orthographic working memory is influenced by phonological assembly deficit in all spoken production tasks (naming, reading aloud and repetition).

# Chapter II

# LITERATURE REVIEW

## Major issues

The reviewed literature on writing processes primarily included studies in English language and most researches used English-speaking participants and the DRM to explore and explain different types of acquired dysgraphia and dyslexia. There is little evidence on cross-linguistic orthographic data using a cognitive neuropsychology model, specifically the DRM, and adapting it from English to other languages that potentially involve challenges and issues. Although researchers think that the basis of writing in all alphabetic languages shares the same process, still other researchers think that different orthographies may be processed differently (Weekes, 2005, 2012).

In order to understand acquired dyslexia and dysgraphia across scripts, it is important to report what is observed in other languages. Even if a disorder can be interpreted with existing CN models, the aim of reporting cases in different languages should not be used to support a “universal” model of reading and writing (Coltheart, 2001), but instead focus on the unique orthographic differences that serve as a basis for hypothesizing about breakdowns within a language.

**Literature Review**

Different cultures introduced different types of scripts to transcribe their oral communication into written language. The writing systems can be divided into alphabetic (sound-based) and non-alphabetic (logographic) scripts (Luzzatti, 2008). The organization of the alphabetic orthography system is based on how the written language (graphemes) predicts the pronunciation of a word. Languages with shallow (or transparent) orthographies such as Italian and Spanish are easy to pronounce based on the written word. In other words, there is one-to-one relationship between letters (graphemes) and sounds (phonemes), and the reading and spelling of words is direct. In contrast, languages with deep (or opaque) orthographies such as English and French are less direct, and reader must learn pronunciations of irregular words. In other words, deep orthographies do not have a one-to-one correspondence between phonemes and graphemes. Some languages such as Semitic languages (Arabic and Hebrew) have mixed (deep and shallow) orthography systems (Katz & Frost, 1992).

Despite the difference in the orthography systems, several studies reported at least one of the two clear cases of dysgraphia (surface and/or phonological) that is seen in English language. These patterns of acquired dyslexia and dysgraphia have been reported in other languages including for example Italian (Luzzatti, Laiacona, Allamano, Tanti, & Inzaghi, 1998; Luzzati, Toraldo, Zonca, Cattani, & Saletta, 2006; Miceli, & Caramazza, 1993 Toraldo, Cattani, Zonca, Saletta, & Luzzatti, 2006), Spanish (Ardila, 1991, Cuetos, 1993; Iribarren, Jarema, & Lecours, 2001), Hebrew (Friedman, 1996; Gviona & Friedmann, 2010), Slovak (Hricova & Weekes, 2012) and Arabic (Beland, &

Mimouni, 2001). Although the characteristics of reading and writing disorders vary across scripts, these reports revealed dissociable symptoms of acquired dyslexia and dysgraphia in quite different languages. The DRM for reading and writing appears to be mandatory even in different orthography systems, but the reliance on each route (lexical - nonlexical) might differ depending on the orthography system of the language. The contrastive studies on acquired reading and writing disorders in languages with different scripts, and/or different degrees of regularity, indicate that the DRM of reading and writing may be generalized across cultures, but that the relative impact of both routes varies substantially from one script to the other (Luzzatti, 2008).

**Arabic Orthography and Morphology Systems**

In the reviewed literature, there are no studies on types of acquired dysgraphia and dyslexia after brain damage in adult Arabic individuals. The comparison of the script systems in English and Arabic reveals differences in the orthographic and morphologic systems. Arabic uses an alphabetic script that is quite transparent for beginning readers. Arabic language is marked by a limited vocalic system with 6 vowels (3 long, 3 short) and a rich consonantal system with 28 letters (see Table 1 for examples). The directionality of using the Arabic orthography system is from right to left in a cursive manner. Letters have more than one written form, depending on the letter position in a word. Short vowels are represented only by added diacritics, not always indicated, and are not part of the alphabet system (Abu-Rabia, 2001). Arabic script, similarly to Hebrew, is labeled to have both deep and shallow orthography; Vowelized

Arabic is considered shallow orthography, and un-vowelized Arabic is considered deep orthography (Abu-Rabia & Taha, 2004). Therefore, individuals are expected to use either route (lexical, sub-lexical) depending on the type of orthography presented (Beland & Mimouni, 2001). Beginners and poor readers read texts with short vowels but adult readers are expected to read texts (books, newspapers and magazines) without short vowels with reliance on context and other resources.. The omission of short vowels results in a large number of homographs (words with same writing form but different meaning). For example: /akala, اكل/ has at least 4 meaning with the same written form. When un-voweled, the four words look exactly the same, but they are pronounced differently with different meanings depending on the context, therefore, Arabic readers rely heavily on context and other textual clues to achieve comprehension (Hansen, 2010).

Table 1

*Grapheme and Phoneme in Arabic Language*

| Consonants | | |
|---|---|---|
| IPA | Arabic Letter(s) | English Phoneme |
| b | ب | b |
| d | د | d |
| dˤ | ض | NA |
| dʒ ~ ʒ ~ g | ج | j ğ |
| ð | ذ | dh ḏ z |
| ðˤ ~ zˤ | ظ | ẓ z |
| f | ف | f |
| h | ه | h |
| ħ | ح | ḥ |
| j | ي | y |
| k | ك | k |
| l | ل | l |
| m | م | m |
| n | ن | n |
| θ | ث | th |
| q | ق | q g |
| r | ر | r |
| s | س | s |
| sˤ | ص | ṣ s |

| Consonants | | |
|---|---|---|
| IPA | Arabic Letter(s) | English Phoneme |
| sˤ | ص | ṣ s |
| ʃ | ش | sh |
| t | ة - ت | t |
| tˤ | ط | ṭ t |
| w | و | w |
| χ | خ | kh ḵ |
| ɣ | غ | gh |
| z | ز | z |
| ʕ | ع | NA |
| ʔ | أ ء | a |
| ɕ | ش | sh š |
| Vowels | | |
| IPA | Arabic Letter(s) | English Phoneme |
| a | ◌َ | a ah |
| i | ◌ِ | e é / i |
| u | ◌ُ | o u ou |
| a: | ا | ā a è e |
| i: | ي | ī i ee |
| u: | و | ū u ō o |

Arabic language is also rich and overtly relies on morphology. Arabic has two main morphological systems, the derivational morphology (called lexical morphology) that is how words are formed, and inflectional morphology that is how words interact with syntax. The derivational morphology contains words consisting of root and word pattern, which differ in their form, function, and distributional characteristics. A root consists of three or four consonants carrying the main meaning of action combined with a word pattern to add more meaning. Word patterns are primarily consist of vowels and occasionally can feature some consonants as well. Arabic roots and patterns cannot be used in isolation; they should be combined together to form verbs or nominal words that are related to the semantic value of the root (Hansen, 2010). Roots carry semantic meanings that are shared to various degrees by their derivatives. For example, the meaning of the root {ktb}“writing”, is inherent in many derivative forms containing this root (e.g.,[kitaab] book; [kitaabah] writing; [katib] writer). Word patterns consist of different combinations of prefixes, infixes, and suffixes that result in a nonlinear morphological structure (Boudelaa et. al., 2009; Hansen, 2010). Word length in Arabic ranges from 3-9 letters and it increases in relation with increased morphological complexity (i.e. roots are short words (3-letters), derivatives longer words (+4-letters).

Arabic morphology has several contrasts with Indo-European morphologies such as English. According to Boudelaa and colleagues (2009), Arabic and English differ in at least three fundamental ways related to the role of morphology. First, Arabic content words have complex morphological structure. Unlike English words, Arabic words feature at least two bound morphemes, a root and a word pattern. This inserting of root and word pattern morphemes in Arabic means that these morphemes are abstract in a way that does not hold for morphemes in concatenate systems such as English, which generally occur as separable individual phonetic forms. Second, morphemes in English are added in a linear manner one after the other (e.g., dark + -ness = darkness); whereas in Arabic, a root like {ktb} (writing) is inserted with a word pattern such that they surface in a discontinuous nonlinear manner in a word like [katab] (write). Third, the two languages rely differently on morphology to encode different aspects of meaning. For example, there are different linguistic procedures that can be used to express the concept of causativety (i.e., causing someone to do or something to happen). There are three major procedures that explain this concept: lexical, syntactic and morphological. English relies least on morphological procedure that combines stems and specific causative morphemes (e.g., widen, shorten). In contrast, Arabic relies only on morphological procedure, where a root is combined with a causative word pattern (e.g., {faʕʕal} active, perfective, causative) to generate forms like [kattab] cause to write, [ʕallam] cause to learn.

Since Arabic morphology plays an important role in the orthographic system, it is very likely that brain lesions could lead to morphological errors. The main source of this assumption about the role of morphology was the analysis of reading errors made by Arabic readers in Abu-Rabia and Taha (2004). Within their study, they found that the morphological errors in reading were the predominant error type among normal and dyslexic readers. These results were explained by the notion that Arabic has rich morphological structures. The existence of visually and phonologically similar words that are related to the same root might cause morphological types of errors in reading words in Arabic. Other researchers (Beland & Mimouni, 2001) found that, within deep dyslexia in Arabic, morphological errors were the main error type that characterizes the inaccuracy of the failure in word recognition.

**Measuring Tools in the Literature**

The most frequent measuring tools reported in the literature, for assessing acquired dysgraphia and dyslexia, are the John Hopkins University Dyslexia and Dysgraphia Batteries (JHUDDB) by Goodman and Caramazza (1986, unpublished, published by Beeson & Hillis, 2000) and the Psycholinguistic Assessments of Language Processing in Aphasia (PALPA) (Kay, Lesser, & Coltheart, 1992). These tools were structured based on the theoretical framework of the DRM model of writing and spelling of single words.

The JHUDDB includes: a) tasks with several sets of items tapping the lexical and the non-lexical routes and the various underlying processing units, b) tasks on writing to dictation, written naming of pictures, transcoding by letter case, and copying, and c) stimulus word lists that vary by grammatical classes such as word length, word frequency, and imageability. The PALPA test, seems to be less frequently used, has been designed as a comprehensive psycholinguistic assessment of language processing in adult acquired aphasia. Intended both as a clinical instrument and research tool, PALPA is a set of resource materials enabling the user to select language tasks that can be tailored to the investigation of an individual patient's impaired and intact abilities. The detailed profile that results can be interpreted within current cognitive models of language. PALPA subtests of writing are similar in structure to the JHUDDB, however, PALPA has limited number of stimuli in each subtest compared to JHUDDB that has more than 350 stimulus in total.

Although the JHUDDB and PALPA tests are frequently used and reported in the dysgraphia literature, the following information about the construct and procedure of these tools is not available:

- Reliability and validity of the tools.
- Standardization and normative data from people both with and without aphasia.
- Psychometric properties
- Scoring protocols

**Aim of the Study**

One of the foundational principles of CN is the “universality assumption” which states that all normal people have the same cognitive system (Coltheart, 2001; Whitworth et al., 2014). However, such an assumption needs to be validated through cross-cultural research. The aim of the current study is to test the universality assumption of the DRM for reading and spelling in Modern Arabic language. Through testing the DRM model in other languages one can look for evidence in support of the architecture of the DRM model/theory and its organization (Olson & Romani, 2011).

**Significance of the study**

The present study has potential benefits for clinical practice. According to researchers, the use of CN models can provide adequate assessment by revealing the precise nature of the disturbance and ultimately deliver adequate treatment design (Rapcsak et al., 2007; Cardell& Chenery, 1999; Rapp, 2005). The current study will also explore the use of case series design as a methodological procedure for testing individuals with aphasia that will highlight the limitations and benefits of the usefulness of case series methods. The study will also design a stimulus-list that will be capable of detecting and distinguishing alexias and agraphias, within the DR model, in Arabic speakers with stroke-induced reading and writing/spelling issues.

**Predictions**

The box and arrow models of the DRM remain a major source of explanatory research. If different modules and connections in this model can be independently impaired, a very large number of possible patterns of performance may result from a lesion. The study will follow the same architecture of the DRM taking into considerations specific variables that hold certain features of the Arabic script. Based on the DRM of reading and writing, the following predictions can be made concerning the performance of AIWA:

1. Predicted performance pattern for reading and spelling via impaired lexical route

   It has been suggested in the literature that the relative involvement of the lexical and the sub-lexical routes in reading and spelling depends on the degree of regularity or transparency in the language. Arabic language is considered a deep orthography for skilled readers that rely on orthographical knowledge. Therefore, one can assume that the reliance on the lexical route will be more frequent, and impairment to this route could possibly yield more surface dyslexia and surface dysgraphia compared to other types of acquired dyslexia and dysgraphia (deep, phonological) seen in English aphasia individuals.

2. Predicted performance pattern for reading and spelling via impaired morphological/semantic system

Arabic morphology is a significant principle of lexical organization, and Arabic surface forms are automatically decomposed into roots (carrying meaning) and word patterns during lexical access. Given that, in Arabic, morphologically related words are also semantically related (Beland & Mimouni, 2001). Studies in English showed the presence of morphological errors combined with phonological and deep dyslexia (Jefferies, Sage, & Ralph, 2007). However, in this study we predict that impaired lexical route will also yield morphological errors, these are reading and spelling errors that still relate morphologically and semantically to the target word such as the word تَنْتَظِرْ /tntadʼr/ waiting) could be read as (/tndʼur/ looking); and the word (أولاد /ςwla:d/ boys) could be spelled as ( وَلَد /wald/ boy).

3. Predicted performance pattern for reading and spelling via impaired orthographic working memory

Word length in Arabic ranges from 3 to 9 letters. We assume that the effect of word length will interfere with processing all stored graphemic representations, irrespective of lexical status (words vs. nonwords), orthographic regularity, and input and output modalities as seen with English speakers. However, in addition, we also predict that morphological variable can covary with the word length effect. Sage and Ellis (2004) argued that representations at the level of the graphemic buffer (GB) are sensitive to lexical factors such as lexical frequency. In this study we assume that

GB is sensitive to morphological complexity because word length in Arabic increases in relation with increased morphology (i.e. roots are short words (3-letters), derivatives longer words (+4-letters). This study will also evaluate another important indicator of OWM deficit that is the serial position effect or what is referred to as "bow-shaped" function (i.e., higher incidence errors in the medial letter position) in both reading and writing.

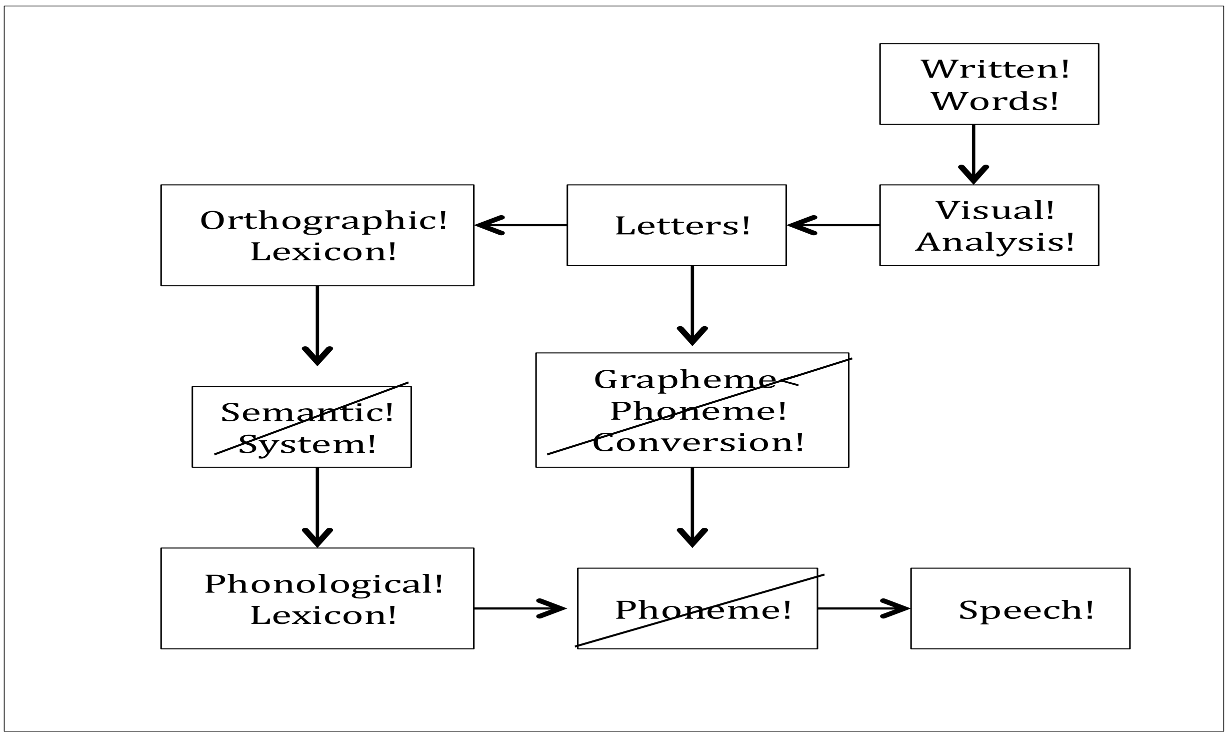


*Figure 4.* The Dual-Route Model (DRM) for reading aloud (adopted from Coltheart et al, 2001; Hillis, 2002). The crossed marks superimposed by the author to predict impairments for reading aloud.

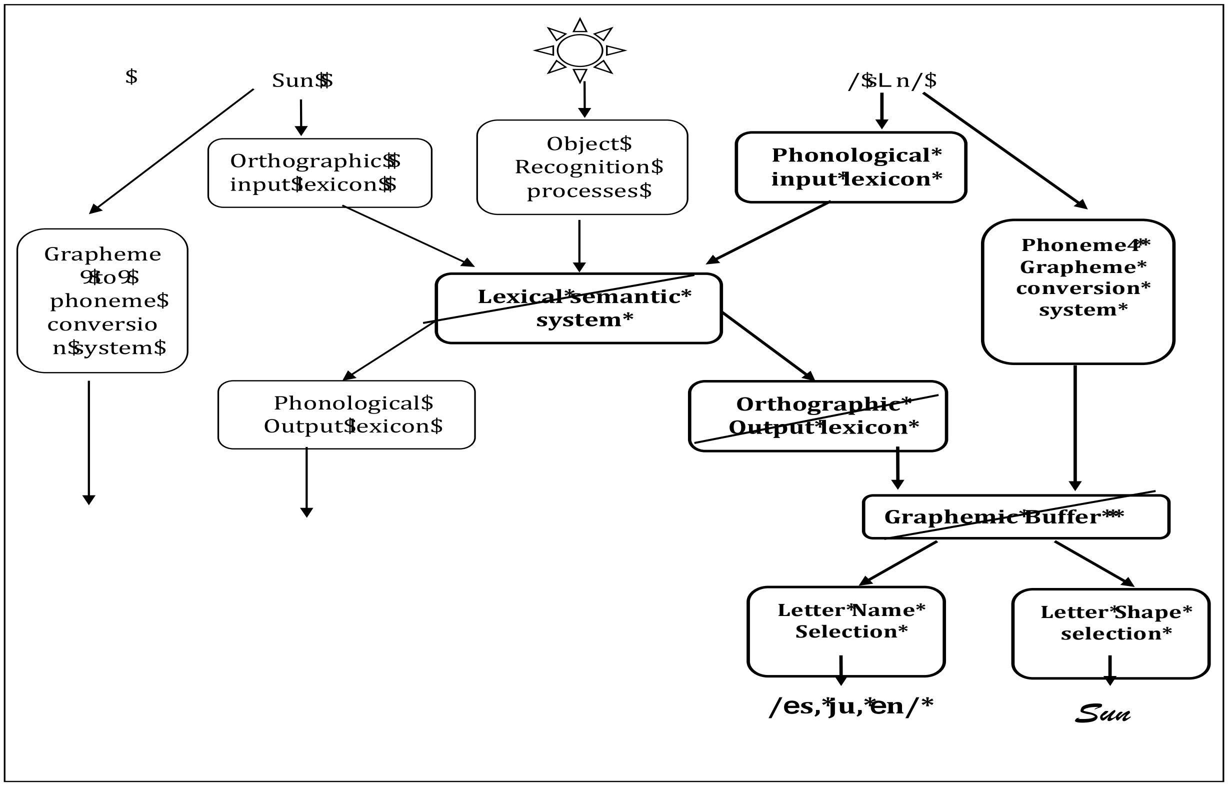


*Figure 5.* The Dual-Route Model (DRM) for spelling (bolded) (Rapp, 2002). The crossed marks superimposed by the author to predict impairments for spelling in AIWA.

**Research Questions**

RQ1- Does lexical route processing influence spelling and reading aloud performance accuracy of Arabic individuals with aphasia (AIWA)?

Hypotheses:

H1a. Surface dyslexia will occur more frequently than other types of dyslexia in AIWA.

H1b. Surface dysgraphia will occur more frequently than other types of dysgraphia in AIWA.

$H1_c$. Spelling accuracy of regularity and lexicality word list will predict the occurrence of surface dysgraphia in AIWA.

$H1_d$. Reading aloud accuracy of regularity and lexicality word list will predict the occurrence of surface dyslexia in AIWA?

RQ2. Does Arabic morphology influence spelling and reading aloud performance accuracy of AIWA?

Hypotheses:

$H2_a$. Rates of morphological error types in writing to dictation will be higher than the other error types.

$H2_b$. Rates of morphological error types in reading aloud will be higher than the other error types.

RQ3. What are the indicators of orthographic working memory (OWM) impairment in acquired dysgraphia and dyslexia in Arabic?

Hypotheses:

$H3_a$. Word length errors will predict spelling accuracy.

$H3_b$. Presence of serial position effect in writing to dictation task.

$H3_c$. Word length errors will predict reading aloud accuracy.

$H3_d$. Presence of serial position effect in reading aloud task.

RQ4. Does morphological complexity influence orthographic working memory?

Hypotheses:

$H4_a$. Complex morphological words will predict spelling accuracy.

$H4_b$. Complex morphological words will predict reading aloud accuracy.

**Variables**

In order to assess the different levels of breakdown using the DRM model, three kinds of independent variables (predictors) are usually reported in the literature. According to Whitworth, Webster, and Howard (2014) the following properties can be used to identify the nature of the underlying impairments: (1) the effects of critical variables, (2) the nature of errors and (3) convergent evidence from different tasks that use common processing components. These independent variables on their own do not provide conclusive evidence, however, together they can provide very strong evidence that allows the clinician to identify impaired processes. These three independent variables will be used to identify the presence of the types of dyslexia and dysgraphia (Dependent variable) seen in AIWA participants.

The independent variables to test reading aloud and spelling for the study will be as follow:

A. Critical variables (Whitworth, Webster, & Howard, 2014):

   A.1. Word frequency: contains high and low frequency words to assess the orthographic output lexicon.

   A.2. Imageability: contains abstract and concrete words to assess the semantic component.

   A.3. Word length: contains words ranging from 3 to 9 letters to assess the graphemic buffer.

   A.4. Word grammatical class: contains nouns, verbs, adjectives and function words to determine the presence of a *grammatical class effect*

A.5. Word Morphology: Adding this variable will be important since Arabic language is rich in morphology. This variable contains words with simple morphology and complex morphology to assess the morphological effect.

B. Lexical Access:

B.1 Word regularity: contains regular (vowelized words- shallow orthography) and irregular (unvowelized words- deep orthography) to assess the orthographic output lexicon or access to it and to determine the presence of a regularity effect.

B.2 Lexicality: contains word and non-words to assess the lexical access.

C. Nature of errors (Whitworth, Webster, & Howard, 2014):

This variable is used in seeking more information to identify the intact and impaired performance in processing. The types of errors could be: semantic, phonological, visual, morphological, or unrelated. For example, semantic errors suggest that the underlying deficit lies in semantic representations. Another example, phonological errors suggest that the underlying deficit lies in phonological input components.

D. Comparisons across tasks (Whitworth, Webster, & Howard, 2014):

Performance on different tasks will be compared to assess whether these tasks share the same information-processing components. The two tasks will be: writing to dictation and reading aloud.

# Chapter III

# METHODS

## Study Design

The current study used case series design to answer the research questions. The utilization of such descriptive study design will help improve trend analyses regarding the outcomes. Case series design preserves and uses individual data by characterizing the distribution of scores and what factors covary with the scores (Schwartz & Dell, 2010). In addition, the aphasia population is heterogonous with huge variability, therefore, case series method concerns for individual's performance rather than group performance.

## Selection of Participants

Those who fulfill the following criteria were admitted to the study: (1) age ranged between 18 and 70 years, (2) literate (preferably monolinguals), (3) native Arabic speakers with Saudi nationality or other regional nationalities with a similar dialect, (4) diagnosis of left hemispheric lesion (stroke) resulting in aphasia, preferably participants had one stroke only, (5) minimum of four weeks post stroke, and (6) did not have any other neurological condition such as dementia, Parkinson’s or Alzheimer’s that will affect test performance.

Pre-assessment information (where this is available) was collected from the participant’s medical history/chart:

- Deficits of visual acuity and/or visual neglect.
- Deficits of hearing.
- Cognitive screening to rule out dementia.
- Language function evaluation to assess level of language in different modalities.
- Magnetic resonance imaging (MRI) or Computed tomography (CT) scans reports and/or images.

**Sampling procedure and Number of Participants**

The study used convenience-sampling technique and subjects were selected based on their convenient accessibility to the researcher.

Fifteen native Arabic individuals with aphasia who met the inclusion criteria were recruited. This sample number was based on two main reasons. First, case series sample number should be 10 or more according to Schwartz and Dell (2010). Second, the average sample number of participants published in articles in Aphasiology Journal between 2013 and 2014 was 14 participants.

**Testing materials**

The testing material of the study was designed by the researcher based on the theoretical framework of the DRM model of writing and spelling of single words. The measuring tool aims to isolate the precise processing locus underpinning the impairment within the framework of the dual-route cognitive model. Designing the measuring tool for assessing writing skills included different measures and levels. The tool was constructed similarly to the John Hopkins University Dyslexia and Dysgraphia Batteries by Goodman and Caramazza (1986, unpublished, published by Beeson & Hillis, 2000) and the Psycholinguistic Assessments of Language Processing in Aphasia (PALPA) (Kay, Lesser, & Coltheart, 1992), taking into consideration language variations and the unique properties of the Arabic language.

The test included a list of words commonly used in the Arabic language and specifically in the Saudi dialect. The tool included word lists representing the critical variables and the lexical access variables. The assessment also involved two tasks, including writing to dictation and reading aloud. The same list of words was used to test reading aloud and writing.

The test lists include 412 words that were obtained from the Buckwalter and Parkinson (2011) book. This book provides a list of the 5,000 most frequently used words in Modern Standard Arabic (MSA) as well as several of the most widely spoken Arabic dialects. Theses words are based on a 30-million-word corpus of Arabic, which includes written and spoken material from the entire Arab world. Appendix 1 has a sample of the testing material.

**Reliability and validity of the testing material.** The process of developing and validating the testing material focused on reducing errors and increasing consistency. Interclass-correlation coefficient (ICC) was used to assess inter-rater reliability. Anonymous three senior speech-language pathologists, who are Arabic native speakers, were included. The raters reviewed all the testing items in the seven lists for familiarity, readability, clarity and comprehension. Appendix 2 provides SPSS outputs for each of the four variables. The raters were asked to rate the words on each list using one to five scale with “1” is lowest and “5” is the highest. ICC results showed statistically significant ($p < .001$) high degree of reliability between raters in familiarity measurement ICC = 0.75, with 95% CI (0.20, 0.95); high reliability in readability measurement ICC= 0.83, with 95% CI (0.37, 0.97); high reliability in clarity measurement ICC= 0.93, 95% CI (0.73, 0.99), and high reliability degree in comprehension measurement ICC= 0.86, with 95% CI (0.46, 0.98).

**Record Forms.** Each record form contains a cover page that shows a detailed participant’s profile and medical information and followed by the consent form and finally the score sheets. The test booklet is designed to enable the examiner to record the response of the participant for each item on each subtest. In order to obtain a total number of correct responses, the scores on each subtest were added together providing a raw score.

All information regarding a participant's profile was collected from the participants' speech-language pathologist, and from the participants or their caregiver. The following information was obtained for each participant to provide the basic case history and participant's profile: Participant's Code/Case Number, age, gender, marital status, nationality, place of birth, place of residency, native language, exposure to other language(s), handedness, educational history, occupational history, medical history, and speech-language history and diagnosis.

**Statistical Methods**

In this study both dependent and independent variables are categorical and thus, non-parametric statistical methods were used to analyze the data. SPSS statistic software version 24 was used to analyze the results.

- Demographic Data: statistical data about the characteristics of the sample, such as the age, gender, education, time post stroke, handedness, site of lesion ...etc.
- Descriptive data: statistical data about the frequencies and percentages for nature of errors and the performance across tasks. Each participant was classified into one of the major dysgraphia and dyslexia patterns through nature of errors analysis.
- A chi-square of difference: was used to compare two or more independent samples on a nominal-level dependent variable. For example, compare individual's performance on short words and long words, high frequency words and low frequency words … etc.

- Logistic regressions: specifically Binary logistic regression was used to predict the probabilities of the different possible outcomes of a categorically dependent variable, given a set of binary categorical independent variables. The logistic regression was applied to the profile of each single subject, to study the effect of different independent variables that might influence individual's performance on spelling and reading aloud accuracy.

**Recruitment Sites**

All patients in speech-language pathology clinics, Aphasia clinic or adult stroke rehabilitation units, who met the selection criteria, were invited to participate from the following institutions:

- King Fahad Medical city (KFMC) – Riyadh, Kingdom of Saudi Arabia
- Sultan Bin Abdulaziz Humanitarian City (SBAHC)– Riyadh, Kingdom of Saudi Arabia.
- King Faisal Specialized Hospital and Research Centre (KFSH&RC)- Riyadh, Kingdom of Saudi Arabia.

**Ethical Approval**

In order to ensure that subjects' rights and welfare were adequately protected, the study protocol was submitted, reviewed and approved by the "Institutional Review Board" (IRB) for Human Subjects Research at Seton Hall University.

Additionally, since the study was carried out at more than one site, ethical permission from the ethical committee of each institute was obtained, see Appendix 3 for IRB letters of approval. King Fahad Medical City (KFMC) IRB #15-435E approved date December 13, 2015; Sultan Bin Abdulaziz Humanitarian City (SBAHC) IRB# 001/2016/28 approved date January 31, 2016; and King Faisal Specialized Hospital and Research Centre (KFSH&RC) IRB# ORA/0807/37- Project # 2161103 approved date May 18, 2016.

After obtaining the hospitals IRB approval in Riyadh, Saudi Arabia, ethical permission from Hackensack University Medical Center, New Jersey, United State was obtained as part of Seton Hall University IRB process. The Study# Pro00006350 has been reviewed and approved via expedited review on April 15, 2016.

**Methods of Recruitment**

All recruitment efforts respected participants' rights to privacy and confidentiality. In each hospital, speech-language pathologist(s) (SLPs) who cover the speech-language clinics, Aphasia clinics, or the rehabilitation units; approached the potential patient and asked if they are interested to participate in the study. Once the patient agrees, primarily, to participate in the study, the principle investigator (PI) came and explained the study in details. The patient must be competent and mentally capable of understanding the facts about the research and making a decision. The PI stated to the participants all necessary information about the study, including the goals and benefits of the study and potential risks.

All potential participants, who agreed to participate, received a "participation information sheet", as well as, "consent form" in Arabic and English Languages. These forms stated the researcher's affiliation with Seton Hall University, purpose of the research, expected testing duration, rights of patients, benefits and risks, and description of the procedure. All participants signed the informed consent form and a copy was filed in each participant's profile.

**Procedure**

Before starting the assessment, the principle investigator (PI) made sure that each participant signed the informed consent; eyeglasses and/or hearing aids are worn, if prescribed; room light and seating position are adequate; and all patients were neurologically stable at the time of testing and were evaluated in the sub-acute or chronic stages of their illness (several months or years post onset).

All testing was done in Arabic language. Participants were asked to write and read lists of words and PI scored participants' performance on the recording sheets. The average number of sessions was four with average test duration of one hour per session. The duration and the number of sessions varied among the participants. After completing the test no further follow up was needed.

## Risks and Benefits

Participating in the study did not put the participants at any potential risk or discomfort. Participation did not benefit the participants in this study directly, but it would hopefully provide new knowledge that could benefit other patients with similar conditions in the future. Participation was completely voluntary and participants had the choice to stop and withdraw from the study at any time he/she want. Participants' decision to withdraw did not, in any way, affect on-going treatment and relationship with their speech-language pathologist(s) (SLPs).

## Ethical Considerations

The principle investigator (PI) was the only person to test the participants and collect the data. The identity of the participants in this study was not revealed by name. Each participant was given a code number for identification and analysis proposes. The performance sheet was confidentially secured in a file and all files were locked in a desk drawer with a key. The data was stored in a secure place and only the principle investigator had access to it.

# Chapter IV

# RESULTS & DISCUSSION

## Section One: Case Reports

In this section, we present a general profile for each of the 15 participants. Table 2 and Table 3 provide demographic data summary on each participant. The language data reported primarily involved informal assessments administered by the participants' speech-language pathologists (SLPs). For each participant, the data reported in this investigation were collected considerably after the cerebrovascular accident (CVA), at a time when they were medically stable. All participants had no premorbid history of reading, writing, or language disorders.

*Abbreviations:* Middle Cerebral Artery (MCA), Magnetic resonance imaging (MRI) or Computed tomography (CT)

Table 2

*Demographic Data*

| Case | Gender | Age | Exposure to other language | Education | Handed-ness |
|---|---|---|---|---|---|
| 0116 | Male | 35 | No | Diploma | Right |
| 0216 | Male | 45 | Yes (English) | Bachelor | Right |
| 0316 | Male | 54 | No | 9th grade | Right |
| 0416 | Female | 53 | No | Diploma | Right |
| 0516 | Male | 44 | Yes (English) | Bachelor | Right |
| 0616 | Female | 48 | No | High School | Right |
| 0716 | Male | 67 | No | Diploma | Right |
| 0816 | Male | 26 | No | High school | Right |
| 0916 | Male | 52 | No | 9th grade | Right |
| 1016 | Female | 43 | Yes (English) | Bachelor | Right |
| 1116 | Male | 49 | Yes (English) | Diploma | Right |
| 1216 | Female | 42 | No | High school | Right |
| 1316 | Female | 52 | No | 9th grade | Right |
| 1416 | Male | 59 | No | Bachelor | Right |
| 1516 | Female | 43 | No | High school | Right |
| Average | M= 9<br>F= 6 | 47.5 Y | Mon= 11<br>Bi = 4 | | |

Note: Male (M), Female (F), Years (Y), Monolinguals (Mon), Bilinguals (Bi)

Table 3

*Demographic Data*

| Case | Time post stroke | Site of lesion | Aphasia Type |
|---|---|---|---|
| 0116 | 3 MM | Left MCA and subcortical (BG) infarction | Subcortical (BG) |
| 0216 | 10 MM | Left MCA, left peri-insular, frontal and superior temporal area. | TCM |
| 0316 | 14 MM | Left MCA | Broca's |
| 0416 | 18 MM | Left MCA | Mild Anomia |
| 0516 | 7 MM | Left MCA, left posterior parietotemporal lobe | Anomia |
| 0616 | 13 MM | Left lateral temporal lobe & precentral gyrus infarct | Jargon |
| 0716 | 2 MM | Left MCA | Anomia |
| 0816 | 12 MM | Left MCA | Broca's |
| 0916 | 8 MM | Left MCA | Anomia |
| 1016 | 60 MM | Left infarction in frontal basal, anterior insular, frontal opercular cortical and subcortical parenchymal. | Anomia |
| 1116 | 12 MM | Left MCA, left posterior frontal-parietal-temporal | Conduction |
| 1216 | 2 MM | Left temporal-parietal lobe, BG | Subcortical (BG) |
| 1316 | 19 MM | Left MCA | Broca's |
| 1416 | 4 MM | Left parietal lobe extending to the postcentral gyrus | Broca's |
| 1516 | 8 MM | Left MCA in anterior superior frontal lobe | TCM |
| Average | 12.8 MM | | |

Note: Months (MM), Middle Cerebral artery (MCA), Basal Ganglia (BG), Transcortical Motor (TCM).

**Case 0116.** A right- handed man from Riyadh. 0116 suffered a CVA in January 2016, at the age of 35, and 3-months before the onset of the study investigation. He held a diploma in information and communication technology (ICT) and had been employed at the Saudi Post Office. The CVA resulted in a large left hemisphere MCA lesion and left subcortical basal ganglia (BG) infarction (see Figure 6(A) for MRI scan). He was monolingual of Arabic language. In February 2016, he was admitted for rehabilitation services. As a result of the CVA; he occasionally used support and assistive devices to walk and lost the use of his right arm below the elbow. Aphasia assessment, using informal testing, revealed a score of 90% accuracy in auditory discrimination of words, and fairly intact auditory comprehension of words and sentences with a score of 90% accuracy. He scored 20% accuracy in naming pictures, and 15% accuracy in responsive naming, and he was able to repeat single words and short sentence with 90% accuracy. He had non-fluent speech with moderate difficulties producing words and sentences in spontaneous speech and word- finding difficulties. Furthermore, his written-word and sentence comprehension was intact, and he showed impaired writing skills. According to a diagnosis by his speech-language pathologist (SLP), 0116 appeared to have anterior capsular/ putaminal aphasia with features from Broca's and trans-cortical motor (TCM) aphasia.

**Case 0216.** A 45 year-old right- handed man from Riyadh. 0216 suffered CVA in June 2016, 10-months prior to the onset of the investigation. He held a Bachelor degree in marketing and he worked as a chief executive officer (CEO) in his own company. Prior to his CVA, he was an excellent public speaker and he was fluent in two languages Arabic (native) and English (second language). Magnetic resonance imaging (MRI) indicated a left MCA, with hyper intensity in left peri-insular, frontal and superior temporal area (see Figure 6(B) for MRI scan). As a result of the stroke, the participants suffered moderate to severe difficulty in spoken language production, primarily characterized by word-finding difficulties and phonological errors. His auditory comprehension was impaired at the phonological level. He showed a deficit in accessing the semantic system from the phonological input lexicon (i.e. word meaning deafness) and he was able to recognize a string of phonemes as a word but unable to auditory comprehend the meaning. Written comprehension was excellent, and he was heavily relying on writing and reading to aid auditory comprehension. His semantic skill was intact and he had intact repetition of words and sentences. According to his SLP, 0216 appeared to have non-fluent trans-cortical motor (TCM) aphasia in addition to the deficit in the phonological input lexicon.

**Case 0316.** A 54-year-old right-handed man from Alkharj. 0316 suffered two CVAs (March 2015 and January 2016), 9 and 2-months prior to the onset of the investigation, respectively. Magnetic resonance imaging (MRI) scans revealed an infarct in the left MCA territory (details on the ischemic CVAs lesions or MRI images were not available). He had right hemiplegia and he was on wheelchair. 0316 held a middle school degree and had worked as a governmental employee for more than 25 years prior to the CVA. He was a monolingual speaker of Arabic language only. Informal aphasia assessment showed intact auditory discrimination with 80% accuracy and intact auditory comprehension with 75% accuracy. He was able to comprehend spontaneous speech and follow conversation. He had severely impaired speech production with impaired picture naming ability. His speech was non-fluent with reduced mean length of utterance (MLU) to 1-2 word per sentence. He had impaired repetition skills with multi-syllabic words and sentences. Word-finding difficulties were noted during his spontaneous speech with features of Apraxia of speech (AOS). 0316's written language comprehension and writing were also impaired. According to his SLP, 0316 appeared to have non-fluent Broca's aphasia.

**Case 0416.** A 53-year-old right-handed woman from Hail. She suffered a CVA in October 2014, 18-months before the onset of the investigation. Prior to the CVA, She held a diploma in computer science and she was a housewife. The participant was a healthy female with no medical history or illness. In September 2014, she was diagnosed with uterine fibroid but she refused any surgical intervention. As a consequence of her excessive vaginal bleeding, in October 2014, she was admitted to the emergency room with severe anemia and right lower limb DVT, pulmonary embolism, weakness of the right side of the body, and ischemic stroke. CT scan revealed left MCA (no images available). She had right lower-limb paralysis and she was on wheelchair and receiving physical therapy. The CVA produced mild spoken-language deficit mainly characterized by hesitation and word-finding difficulties, though she made no semantic or phonological errors, and her word picture naming was 100% correct. Her auditory discrimination for words was within the normal age and education level. Further, her auditory sentence comprehension was also intact with a score of 90% accuracy. Her repetition skill was fairly intact and her written-word comprehension was within normal age and education level. According to her SLP, 0416 exhibits the characteristics of mild fluent anomic aphasia.

**Case 0516.** A 44 year-old right- handed man from Riyadh. He suffered a CVA in September 2015, 7-months before the onset of the investigation. MRI scans revealed ischemic infarct in the left middle cerebral artery territory involving the left posterior parietotemporal lobe with minimal foci of micro hemorrhages (see Figure 6(C)). He held a Bachelor degree in medicine and he worked as a general surgery MD consultant. He was a bilingual speaker of Arabic and English, although he had almost exclusively spoke English in his work. After his CVA, he took administrative duties in his work and focused on receiving extensive physical, occupational and speech therapy sessions, and he plans to go back for practice when he recovers completely. No physical weaknesses were reported. Language assessment revealed intact auditory discrimination and auditory comprehension with scores within normal age and education level. His language production skills were affected as a result of the CVA. Although his word-picture naming was 70% correct, his spontaneous speech was marked by hesitations and word finding difficulties. According to his SLP, 0516 appeared to have moderate fluent anomic aphasia.

**Case 0616.** A 48-year-old right-handed woman from Riyadh. She is known case of Moya-Moya disease resulted in multiple strokes. 0616 was diagnosed with moya-moya disease in April 2015. She went to Weill Cornell Medical Center, NYC, USA, and she did two bilateral encephalo-duro-arterio-synangiosis (EDAS) surgeries (December 2015, January 2016). She held a high school degree and she was a housewife. She was monolingual to Arabic language. Speech assessment in 28 April 2015 (before her surgeries) reveled anomic aphasia, delayed responses, and jargon speech. Her multiple CVAs left her with right-hand paralysis and she was able to walk independently with mild right lower-limb paresis. The study investigation was administered 14-months after her CVAs. MRI scan in 12 May 2015 revealed infarction of the left lateral temporal lobe and left precentral gyrus. In addition, there is persistent enchphalomalacia of bilateral corona radiated and basal ganglia, compatible with chronic infarcts (no images available). The CVA produced fluent spoken-language characterized by word finding difficulties, meaningless phrases, incoherently arranged known words, true neologisms (words not phonemically or semantically-related to the target) intermixing real words and nonsense words and using real words in incorrect situations. She had poor word picture naming, impaired repetition, and inadequate and uncoordinated non-verbal agility. Her auditory discrimination for words was functional. According to her SLP, 0516 exhibits the characteristics of fluent neologistic jargon aphasia.

**Case 0716.** A 67-year-old right-handed man from Riyadh. He is known case of rheumatic heart disease post valve replacement. He suffered a CVA in February 2016, 2-months before the investigation. Prior to the CVA, 0716 held a diploma and worked in National Guard for almost 30 years and he retired before the stroke. CT scan revealed left MCA as seen in Figure 6(D). The CVA produced mild spoken-language deficit mainly characterized by hesitation and word-finding difficulties. He showed reduced performance on naming pictures with 70% accuracy. His auditory discrimination for words was within the normal range, and his auditory sentence comprehension was also intact with a score of 90% accuracy. His repetition skill was intact and his written-word comprehension was within normal limit. According to his SLP, 0716 exhibits the characteristics of mild fluent anomic aphasia.

**Case 0816.** A 26-year-old right-handed man from Riyadh. He suffered a CVA in May 2016, 12-months before the onset of the investigation. Prior to the CVA, 0816 held a high school degree and he was solider in the ministry of defense. He was a monolingual speaker of Arabic language only. The participant was a healthy male with no medical history or illness. CT scan revealed left MCA (details on the ischemic CVAs lesions or MRI images were not available). He had right side hemiplegia and he was on wheelchair and receiving physical therapy. Informal aphasia assessment showed intact auditory discrimination with 80% accuracy and intact auditory comprehension with 80% accuracy. He was able to comprehend spontaneous speech and follow conversation. He had severely impaired speech production (apraxia of speech AOS) with impaired picture naming ability. His speech was non-fluent with reduced mean length of utterance (MLU) to two-word per sentence. He had impaired repetition skills and his written language comprehension and writing were also impaired. According to his SLP, 0816 appeared to have non-fluent Broca's aphasia.

**Case 0916.** A 52-year-old right-handed man from Riyadh. He suffered a CVA in October 2015, 8-months before the investigation. Prior to the CVA, he held a middle school degree and he was a governmental employee in the National Guard. CT scan revealed a lesion in the left medial cerebral artery of the left hemisphere (no images or report was available). The CVA produced mild spoken-language deficit mainly characterized by word-finding difficulties, though his word picture naming was 100% correct. His auditory discrimination for words and auditory sentence comprehension was within the normal range. His repetition skill was fairly intact and his written-word comprehension was within normal limit. According to his SLP, 0916 exhibits the characteristics of mild fluent anomic aphasia.

**Case 1016.** A 43-year-old right-handed woman from Hail. She suffered a CVA almost 60-months before the onset of the investigation. Prior to the CVA, she held a Bachelor degree in English literature and worked as an English teacher for elementary grades. She was a bilingual speaker of Arabic and English (second Language), and she almost exclusively spoke English in her work. However after the CVA, she had reduced recovery in her second language and she changed her teaching subject from English to

Arabic and resumed to teach elementary grade students. The participant was a healthy female with no medical history or illness. CT scan revealed low attenuation with tissue swelling consistent with infarction in the left-sided frontal basal, anterior insular, and frontal opercular cortical and subcortical parenchymal (see Figure 6(E)). The CVA produced mild spoken-language deficit mainly characterized by word-finding difficulties. Her auditory discrimination for words and auditory sentence comprehension were within the normal range. Her repetition skill was fairly intact and her written-word comprehension was within normal limit. According to her SLP, 1016 exhibits the characteristics of mild fluent anomic aphasia.

**Case 1116.** A 49-year-old right-handed man from Dammam. He suffered a CVA in June 2015, 12-months before the investigation. Prior to the CVA, he held a diploma and he worked as a safety and security guard in the safety department at King Faisal Specialized Hospital. The participant was a healthy male with no medical history or illness. In June 2015, he was on night-shift duty in the Emergency room where he suddenly collapsed and lost his conciseness. He was diagnosed with ischemic stroke and MRI scan as seen in Figure 6(F) revealed left posterior frontal-parietal-temporal lesion with abnormal high T2/FLAIR signal intensities corresponding to MCA infarction, involving the frontal and parietal operculum, external capsule, posterior limb of internal capsule and the thalamus of the left hemisphere, causing midline shift of 1.2 cm to the right. The participant showed functional auditory comprehension, fluent expressive language with naming difficulties, paraphasias and circumlocutions. His repletion was good at word and sentence levels. According to his SLP, 1116 exhibits the characteristics of fluent conduction aphasia.

**Case 1216.** A 42-year-old right-handed woman from Hail. She suffered intra-cerebral hemorrhage in May 2016, and underwent a decompressive craniotomy. The study investigation was administered 2-months after the CVA. 1216 finished her high school and she was a housewife. MRI scan revealed evidence of crainectomy at the left parietal and frontal bones with multiple hemorrhagic foci seen in the left temporal lobe and the left basal ganglia. Edematous change was also seen at the left temporal and left parietal lobes (see Figure 6(G)). She had right upper-limb paresis and lower-limb paralysis and she was on wheelchair and receiving physical therapy. The CVA produced mild auditory comprehension deficit mainly manifested at sentence level and conversational level. Her speech output was fluent with multiple verbal paraphasias and phonological neologisms. Her repetition skill was fairly intact at word level but sentence repetition was impaired. According to her SLP, 1216 exhibits the characteristics of subcortical posterior capsular/ putaminal aphasia as her profile of speech and language characteristics were similar to the profile of both Wernicke's and Broca's aphasia.

**Case 1316.** A 52-year-old right-handed woman from Riyadh. She suffered an intra-cerebral hemorrhagic stroke in January 2015, 19-months before the investigation. She completed middle school and she was a housewife. Brain imaging revealed left MCA (details on the brain lesion and images were not available). She had right hemiplegia and she was on wheelchair. The CVA produced moderately severe spoken-language deficit with reduced verbal output at the spontaneous speech level. She had fairly intact picture naming and single- word repletion skills. Her auditory discrimination for words and auditory sentence comprehension were within the normal range. According to her SLP, 1316 exhibits the characteristics of moderate non-fluent Broca's aphasia.

**Case 1416.** A 59-year-old right-handed man from Riyadh. He suffered intra-cerebral hemorrhagic stroke in 18 March 2016, and underwent a decompressive craniotomy. The study investigation was administered 4-months after the CVA. Prior to the CVA, he held a Bachelor degree in Shariaah law and he was the judge and the president of the prime court in Riyadh. He retired one year before his stroke. MRI scan done postsurgical evacuation of the left parietal hematoma revealed moderate sized resection cavity within the left parietal lobe extending to the level of the postcentral gyrus, that is filled with CSF signal of fluid (see Figure 6(H)). The CVA produced moderately severe spoken-language deficit mainly characterized by hesitation and word-finding difficulties. His auditory discrimination for words was within the normal range. Further, his auditory sentence comprehension was also intact with a score of 90% accuracy. His repetition skill was impaired and his written-word comprehension was within normal limit. According to his SLP, his linguistic ability recovered from Mixed aphasia to the characteristic of non-fluent Broca's aphasia.

**Case 1516.** A 43-year-old right-handed woman from Riyadh. She suffered a CVA in December 2015, 8-months before the onset of the investigation. 1516 completed her high school and she was a housewife. She occasionally wrote poems and journals. The participant was a healthy female with no medical history or illness. In 12 December 2015, she had sudden loss of consciousness and collapsed at her home where then rushed to the emergency room and diagnosed with ischemic stroke. Medical investigation and work-up for stroke in young patient reveled the she had Systemic Lupus Erythematosus (SLE).  MRI scan showed left MCA and hyperdensity in the anterior superior frontal lobe (see Figure 6(I)). The CVA produced severe spoken-language deficit with poor performance on picture naming and difficulty producing spontaneous speech with short utterances (usually 1-2 words) long. Her repetition skill was intact at words and sentences levels. She had good auditory comprehension and auditory discrimination. Further, her written-word comprehension was within normal limit. According to her SLP, 1516 exhibits the characteristics of moderate severe non-fluent trans-cortical motor (TCM) aphasia.

In sum, all 15 participants were right-handed, literate individuals who suffered language deficits subsequent to CVAs. The 15 participants had some degree of spoken production difficulty, ranging from mild to severe. In contrast, they were all diagnosed with either mild or intact auditory comprehension. The subsequent sections provide detailed evaluations of their writing to dictation and reading aloud performance, which is the focus of this study.

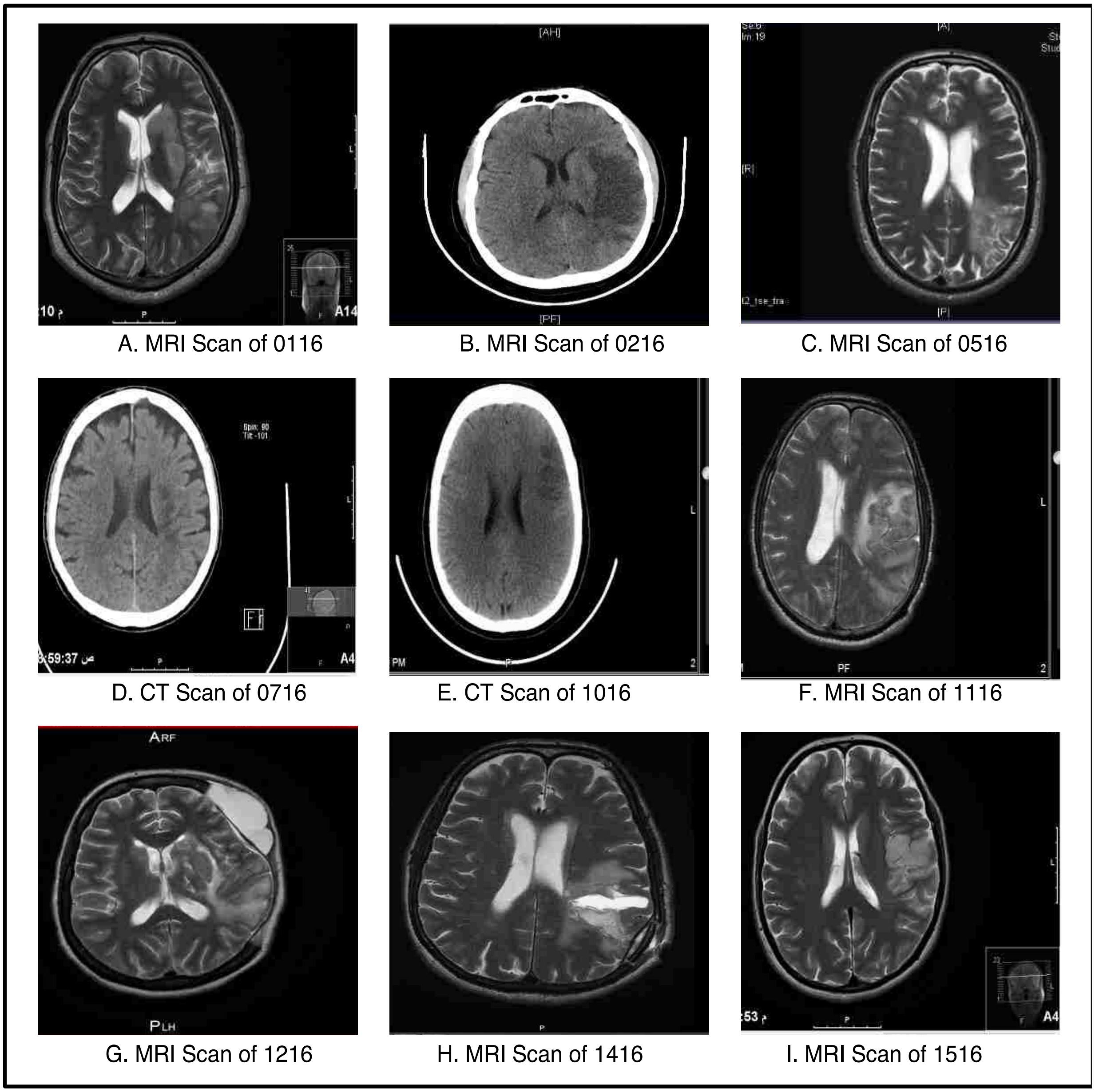


*Figure 6.* MRI and CT Scan images for nine participants.

**Section Two: Writing to Dictation Performance**

Spelling performance analysis is the focus of this section. Raw scores and error patterns of each participant were used independently in the statistical analysis. Chi-square of difference and logistic regression were implemented followed by the localization of deficit and the qualitative pattern of spelling errors.

**1- Chi-square of difference.** The chi square statistics was performed to see if there was a difference in spelling performance between two levels in each independent variable. Before we compute the chi-square test, several assumptions were tested and met: Nominal level variables, random samples, the independence of data (each entity contributes to only one cell of the contingency table so the chi-square test cannot be performed on a repeated-measure design), and the expected frequencies were greater than 5 as the chi-square shows considered 2x2 tables.

***Analysis 1a: Performance on lexicality list.*** Table 4 shows that all subjects were unable to spell non-words and there was a statistically significant difference ($p < .05$) on spelling words compared to spelling non-words. Exception to this was subjects 0216, 0316 and 1316 that had incorrect responses and scored 0 in all stimuli.

Table 4

*Lexicality list, contrasting words and non-words*

| Case | Words 40 | | Non-Words 32 | | Analysis |
|---|---|---|---|---|---|
| | Correct | % | Correct | % | |
| **0116** | 24 | 60 | 2 | 6 | **$X^2$ = 22.26, df (1), p < .05** |
| 0216 | 4 | 10 | 0 | 0 | Fisher's Exact, p = .12 |
| 0316 | 0 | 0 | 0 | 0 | NA |
| **0416** | 40 | 100 | 22 | 69 | **$X^2$ = 14.52, df (1), p < .05** |
| **0516** | 38 | 95 | 12 | 38 | **$X^2$ = 27.7, df (1), p < .05** |
| **0616** | 7 | 18 | 0 | 0 | **Fisher's Exact, p < .05** |
| **0716** | 33 | 83 | 0 | 0 | **$X^2$ = 48.74, df (1), p < .05** |
| **0816** | 13 | 33 | 0 | 0 | **$X^2$ = 12.69, df (1), p < .05** |
| **0916** | 19 | 48 | 6 | 19 | **$X^2$ = 6.48, df (1), p < .05** |
| **1016** | 37 | 93 | 14 | 55 | **$X^2$ = 20.45, df (1), p < .05** |
| **1116** | 19 | 48 | 0 | 0 | **$X^2$ = 29.22, df (1), p < .05** |
| **1216** | 17 | 43 | 4 | 12 | **$X^2$ = 7.75, df (1), p < .05** |
| 1316 | 0 | 0 | 0 | 0 | NA |
| **1416** | 21 | 53 | 0 | 0 | **$X^2$ = 23.75, df (1), p < .05** |
| **1516** | 27 | 68 | 0 | 0 | **$X^2$ = 34.56, df (1), p < .05** |

Note: Significant differences are denoted in **bold (P<.05)**. Statistical tests were chi-square, except for comparisons with cell values smaller than 5, which were computed with Fisher's Exact. NA = Not Available.

***Analysis 1b: Performance on word frequency list.*** The overall results in Table 5 show no statistical differences when contrasting spelling of high and low frequency words. Only participants 0816, 1116, 1216, and 1416 had statistically significant difference.

Table 5

*Word Frequency list, contrasting high frequency and low frequency words*

| Case | High Frequency 95 | | Low Frequency 90 | | Analysis |
|---|---|---|---|---|---|
| | Correct | % | Correct | % | |
| 0116 | 53 | 55 | 46 | 50 | $X^2$ = .41, df (1), p= .57 |
| 0216 | 23 | 24 | 17 | 19 | $X^2$ = .78, df (1), p= .38 |
| 0316 | 4 | 4 | 1 | 1 | NA |
| 0416 | 95 | 100 | 89 | 98 | Fisher Exact, p= .75 |
| 0516 | 78 | 80 | 67 | 75 | $X^2$ = 1.15, df (1), p= .28 |
| 0616 | 12 | 12 | 7 | 7 | $X^2$ = 1.89, df (1), p= .17 |
| 0716 | 61 | 62 | 47 | 51 | $X^2$ = 2.68, df (1), p= .10 |
| **0816** | 28 | 30 | 13 | 14 | **$X^2$ =12.89, df (1), p < .05** |
| 0916 | 45 | 46 | 30 | 33 | $X^2$ = 3.75, df (1), p= .053 |
| 1016 | 85 | 90 | 80 | 90 | $X^2$ = .014, df (1), p= .91 |
| **1116** | 50 | 52 | 25 | 27 | **$X^2$ = 11.72, df (1), p < .05** |
| **1216** | 36 | 37 | 20 | 22 | **$X^2$ = 5.35, df (1), p < .05** |
| 1316 | 4 | 4 | 2 | 2 | NA |
| **1416** | 58 | 60 | 38 | 63 | **$X^2$ = 5.72, df (1), p < .05** |
| 1516 | 67 | 70 | 59 | 62 | $X^2$ = 1.06, df (1), p= .30 |

Note: Significant differences are denoted in **bold (P<.05)**. Statistical tests were chi-square, except for comparisons with cell values smaller than 5, which were computed with Fisher's Exact. NA = Not Available.

***Analysis 1c: Performance on regularity list.*** The overall results seen in Table 6 show that 11 subjects did not have statistically significant difference in spelling vowelized or non-vowelized words. Only four subjects (0161, 0916, 1016 and 1516) had significantly difference in spelling, with high performance on un-vowelized words compared to low performance on spelling vowelized words.

Table 6

*Regularity list, contrasting vowelized and un-vowelized words*

| Case | Vowelized 30 | | Un-vowelized 30 | | Analysis |
|---|---|---|---|---|---|
| | Correct | % | Correct | % | |
| **0116** | 11 | 37 | 20 | 67 | **$X^2 = 5.41$, df (1), $p < .05$** |
| 0216 | 10 | 33 | 15 | 50 | $X^2 = 1.71$, df (1), p= .19 |
| 0316 | 0 | 0 | 3 | 10 | NA |
| 0416 | 25 | 83 | 30 | 100 | Fisher's Exact test, p = .052 |
| 0516 | 21 | 70 | 27 | 90 | $X^2 = 3.75$, df (1), p= .053 |
| 0616 | 2 | 7 | 3 | 10 | $X^2 = 0.22$, df (1), p= .62 |
| 0716 | 21 | 70 | 24 | 80 | $X^2 = 0.8$, df (1), p= .37 |
| 0816 | 2 | 7 | 5 | 17 | $X^2 = 1.46$, df (1), p= .23 |
| **0916** | 9 | 30 | 17 | 60 | **$X^2 = 4.34$, df (1), $p< .05$** |
| **1016** | 23 | 77 | 30 | 100 | **Fisher's Exact, $p < .05$** |
| 1116 | 18 | 60 | 21 | 67 | $X^2 = 0.29$, df (1), p= .59 |
| 1216 | 9 | 30 | 14 | 43 | $X^2 = 1.15$, df (1), p= .28 |
| 1316 | 0 | 0 | 4 | 12 | NA |
| 1416 | 24 | 80 | 22 | 73 | $X^2 = 0.37$, df (1), p= .54 |
| **1516** | 17 | 60 | 26 | 87 | **$X^2 = 6.65$, df (1), $p < .05$** |

Note: Significant differences are denoted in **bold (P<.05)**. Statistical tests were chi-square, except for comparisons with cell values smaller than 5, which were computed with Fisher's Exact. NA = Not Available.

***Analysis 1d: Performance on word length list.*** In this analysis, short words consist of 3, 4, 5 and 6 letter words (n=55), and the long words consist of 7, 8, and 9-letter words (n=40). The results in Table 7 show that all subjects had statistically significant difference (p < .05) in spelling short words compared to long words. Subjects 0316 and 1516 were excluded as they had incorrect responses with almost 0 performance in the word length category. Also subject 0416 was excluded as she had almost 100% performance on the word length category.

Table 7

*Word Length, contrasting short words (SW) and long words (LW)*

| Case | SW 55 | | LW 40 | | Analysis |
|---|---|---|---|---|---|
| | Correct | % | Correct | % | |
| **0116** | 28 | 51 | 8 | 20 | **$X^2$ = 13.60, df (1), p < .05** |
| **0216** | 27 | 49 | 2 | 5 | **$X^2$ = 23.96, df(1), p < .05** |
| 0316 | 2 | 4 | 0 | 0 | NA |
| 0416 | 55 | 100 | 39 | 98 | NA |
| **0516** | 45 | 82 | 22 | 55 | **$X^2$ = 8.13, df (1), p < .05** |
| 0616 | 5 | 9 | 0 | 0 | Fisher's Exact, p = 0.6 |
| **0716** | 33 | 60 | 16 | 40 | **$X^2$ = 5.92, df (1), p < .05** |
| **0816** | 9 | 16 | 0 | 0 | **$X^2$ = 5.84, df (1), p < .05** |
| **0916** | 24 | 44 | 6 | 15 | **$X^2$ = 10.82, df (1), p < .05** |
| **1016** | 54 | 100 | 31 | 78 | **$X^2$ = 19.90, df (1), p < .05** |
| **1116** | 25 | 45 | 3 | 8 | **$X^2$ = 18.47, df (1), p < .05** |
| **1216** | 13 | 24 | 0 | 0 | **$X^2$ = 12.23, df (1), p < .05** |
| 1316 | 3 | 4 | 0 | 0 | NA |
| **1416** | 35 | 62 | 5 | 13 | **$X^2$ = 26.75, df (1), p < .05** |
| **1516** | 47 | 85 | 12 | 30 | **$X^2$ = 40.38, df (1), p < .05** |

Note: Significant differences are denoted in **bold (P<.05)**. Statistical tests were chi-square, except for comparisons with cell values smaller than 5, which were computed with Fisher's Exact. NA = Not Available.

***Analysis 1e: Performance on morphological list.*** In the morphological list analysis, words were grouped into two categories: simple words that have short words configuration of 3-4-5-letters (SSW n=30), and complex words that has longer words of 6 and 7 letters (CLW n=20). This analysis used the derivational morphological word list only. Table 8 shows the results of nine subjects, where they all had a statistically significant difference in spelling simple-short words compared to complex-long words. This is also consistent with the results seen in Table 7, were subjects showed significant difference in word length.

Table 8

*Morphological list, contrasting simple-short words (SSW) and complex-long words (CLW)*

| Case | SSW 30 | | CLW 20 | | Analysis |
|---|---|---|---|---|---|
| | Correct | % | Correct | % | |
| **0116** | 17 | 57 | 4 | 20 | **$X^2$ = 6.62, df (1), p < .05** |
| **0216** | 25 | 83 | 8 | 40 | **$X^2$ = 10.04, df (1), p < .05** |
| 0316 | 0 | 0 | 0 | 0 | NA |
| 0416 | 30 | 100 | 20 | 100 | NA |
| 0516 | NA | NA | NA | NA | NA |
| 0616 | 4 | 13 | 0 | 0 | NA |
| **0716** | 26 | 87 | 5 | 25 | **$X^2$ = 19.37, df (1), p < .05** |
| **0816** | 10 | 33 | 0 | 0 | **$X^2$ = 8.33, df (1), p < .05** |
| **0916** | 19 | 63 | 2 | 10 | **$X^2$ = 14.01, df (1), p < .05** |
| **1016** | 30 | 100 | 16 | 80 | **Fisher's Exact, p < .05** |
| **1116** | 12 | 40 | 2 | 10 | **$X^2$ = 5.36, df (1), p < .05** |
| **1216** | 13 | 43 | 1 | 5 | **$X^2$ = 8.75, df (1), p < .05** |
| 1316 | 6 | 20 | 0 | 0 | NA |
| 1416 | NA | NA | NA | NA | NA |
| **1516** | 25 | 83 | 10 | 50 | **$X^2$ = 6.35, df (1), p < .05** |

Note: Significant differences are denoted in **bold (P<.05)**. Statistical tests were chi-square, except for comparisons with cell values smaller than 5, which were computed with Fisher's Exact. NA = Not Available.

In summary, the chi-square of difference analysis showed that the three independent variables: lexicallty, word length and derivational morphology, had an overall significant difference in spelling performance.

**2- Logistic regression.** Binary logistic regression analysis was applied to the profile of each participant to study the effect of different variables that might influence spelling accuracy. The dependent variable for each stimulus was either 0 (error) or 1 (correct). The independent variables were all nominal with two categories: 1) Lexicality (words – nonwords), 2) Word frequency (high- low), 3) Regularity (vowelized- unvowelized), 4) Imageability (concrete- Abstract), 5) Word length (short- long), 6) Derivational morphology (simple- complex), and 7) inflectional morphology (verbs- nouns). Table 16 provides a descriptive summary for the binary logistic regressions.

***Analysis 2a: Effect of lexicality on spelling accuracy.*** As seen in Table 9, lexicality has statistically significant predictive effect on spelling accuracy for only 4 subjects (0116-0516-1016-1216) ($p < .05$). This independent variable did not show any effect on predicting the spelling performance of the other 11 participants.

Table 9

*Lexicality as predictor to spelling accuracy*

| Case | Words 40 | | Non-words 32 | | B | Wald | P | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| | Correct | Error | Correct | Error | | | | |
| **0116** | 24 | 16 | 2 | 30 | 3.11 | 15.21 | **.000** | .41 |
| 0216 | 4 | 36 | 0 | 32 | 19.01 | 0.00 | .99 | .19 |
| 0316 | 0 | 40 | 0 | 32 | - | - | NA | - |
| 0416 | 40 | 0 | 22 | 10 | 20.41 | 0.00 | .99 | .41 |
| **0516** | 38 | 2 | 12 | 20 | 3.45 | 18.19 | **.000** | .49 |
| 0616 | 7 | 33 | 0 | 32 | 19.65 | 0.00 | .99 | .25 |
| 0716 | 33 | 7 | 0 | 32 | 22.75 | 0.00 | .99 | .77 |
| 0816 | 13 | 27 | 0 | 32 | 20.47 | 0.00 | .99 | .35 |
| 0916 | 19 | 21 | 6 | 26 | 21.10 | 0.00 | .99 | .47 |
| **1016** | 37 | 3 | 14 | 18 | 2.76 | 15.67 | **.000** | .37 |
| 1116 | 19 | 21 | 0 | 32 | 21.10 | 0.00 | .99 | .47 |
| **1216** | 17 | 23 | 4 | 28 | 1.64 | 6.96 | **.01** | .16 |
| 1316 | 0 | 40 | 0 | 32 | - | - | NA | - |
| 1416 | 21 | 19 | 0 | 32 | 21.30 | 0.00 | .99 | .51 |
| 1516 | 27 | 13 | 0 | 32 | 21.93 | 0.00 | .99 | .63 |

Note: P value in **bold** reflect significant results **(P<.05)**. NA = Not Available.

***Analysis 2b: Effect of word Frequency on spelling accuracy.*** As seen in Table 10, word frequency has statistically significant predictive effect on spelling accuracy for only 4 subjects (0816-1116-1216-1416) ($p < .05$). This independent variable did not show any effect on predicting the spelling performance of the other 11 participants.

Table 10

*Word frequency as predictor to spelling accuracy*

| Case | HF 45 | | LF 45 | | B | Wald | P | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| | Correct | Error | Correct | Error | | | | |
| 0116 | 33 | 12 | 29 | 16 | -0.42 | 0.83 | .36 | .013 |
| 0216 | 6 | 39 | 5 | 40 | -0.21 | 0.10 | .78 | .002 |
| 0316 | 2 | 43 | 1 | 44 | -0.72 | 0.33 | .57 | .015 |
| 0416 | 45 | 0 | 43 | 2 | -18.14 | 0.000 | .99 | .161 |
| 0516 | 43 | 2 | 39 | 6 | -1.19 | 2.00 | .16 | .056 |
| 0616 | 9 | 36 | 5 | 40 | -0.69 | 1.32 | .251 | .026 |
| 0716 | 35 | 10 | 24 | 21 | -1.12 | 5.75 | .02 | .09 |
| **0816** | 21 | 24 | 10 | 35 | -1.12 | 5.75 | **.02** | .09 |
| 0916 | 23 | 22 | 16 | 29 | -0.64 | 2.19 | .14 | .03 |
| 1016 | 42 | 3 | 38 | 7 | -0.95 | 1.71 | .19 | .04 |
| **1116** | 31 | 14 | 17 | 28 | -1.29 | 8.45 | **.004** | .13 |
| **1216** | 28 | 17 | 16 | 29 | -1.09 | 6.25 | **.01** | .09 |
| 1316 | 2 | 43 | 1 | 44 | -0.72 | 0.33 | .57 | .02 |
| **1416** | 34 | 11 | 23 | 22 | -1.08 | 5.62 | **.02** | .09 |
| 1516 | 36 | 9 | 31 | 14 | -0.59 | 1.44 | .23 | .02 |

Note: P value in **bold** reflect significant results **(P<.05)**. NA = Not Available.

***Analysis 2c: Effect of regularity on spelling accuracy.*** When binary logistic regression was computed on the regularity list, results were statistically not significant for 12 participants as shown in Table 11. Regularity variable was statistically significant predictor ($p < .05$) in spelling accuracy for three subjects 0116, 0916, and 1516.

Table 11

*Regularity as predictor to spelling accuracy*

| Case | Vowelized 30 | | Un-vowelized 30 | | B | Wald | P | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| | Correct | Error | Correct | Error | | | | |
| **0116** | 11 | 19 | 20 | 10 | -1.24 | 5.24 | **.02** | .12 |
| 0216 | 10 | 20 | 15 | 15 | -0.69 | 1.69 | .19 | .04 |
| 0316 | 0 | 30 | 3 | 27 | -19.01 | 0.00 | NA | .21 |
| 0416 | 25 | 5 | 30 | 0 | -19.59 | 0.00 | NA | .27 |
| 0516 | 21 | 9 | 27 | 3 | -1.35 | 3.44 | .06 | .09 |
| 0616 | 2 | 28 | 3 | 27 | -1.03 | 1.37 | NA | .05 |
| 0716 | 21 | 9 | 24 | 6 | -0.54 | 0.79 | .37 | .02 |
| 0816 | 2 | 28 | 5 | 25 | -1.03 | 1.37 | NA | .05 |
| **0916** | 9 | 21 | 17 | 13 | -1.12 | 4.23 | **.04** | .09 |
| 1016 | 23 | 7 | 30 | 0 | -20.01 | 0.00 | NA | .32 |
| 1116 | 18 | 12 | 21 | 9 | -0.44 | 0.66 | .48 | .02 |
| 1216 | 9 | 21 | 14 | 16 | -0.71 | 1.74 | .19 | .04 |
| 1316 | 0 | 30 | 4 | 26 | -19.33 | 0.00 | NA | .24 |
| 1416 | 24 | 6 | 22 | 8 | 0.38 | 0.37 | .54 | .01 |
| **1516** | 17 | 13 | 26 | 4 | -1.60 | 6.06 | **.01** | .16 |

Note: P value in **bold** reflect significant results **(P<.05)**. NA = Not Available.

***Analysis 2d: Effect of word length on spelling accuracy.*** Similar to the chi-square analysis, short words consists of 3, 4, 5 and 6 letter words (n=55), and long words consists of 7, 8, and 9- letter words (n=40). In the binary logistic analysis reported in Table 12, word length was statistically significant predictor (p <.05) in eight subjects. Binary logistic regression was not computed for Subjects (0316, 0616, 0816, 1316) as they had no responses, and subject (0416) as she had 100% performance.

Table 12

*Word Length as predictor to spelling accuracy*

| Case | SW 55 | | LW 40 | | B | Wald | P | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| | Correct | Error | Correct | Error | | | | |
| **0116** | 28 | 27 | 8 | 32 | 1.42 | 8.84 | **.003** | .13 |
| **0216** | 27 | 28 | 2 | 38 | 2.91 | 14.12 | **.000** | .32 |
| 0316 | 2 | 53 | 0 | 40 | 17.93 | 0.00 | NA | .13 |
| 0416 | 55 | 0 | 39 | 1 | 17.54 | 0.00 | NA | .17 |
| **0516** | 45 | 10 | 22 | 18 | 1.30 | 7.61 | **.01** | .115 |
| 0616 | 5 | 50 | 0 | 40 | 18.90 | 0.00 | NA | .17 |
| 0716 | 33 | 22 | 17 | 23 | 0.71 | 2.82 | NA | .04 |
| 0816 | 9 | 46 | 0 | 40 | 19.57 | 0.00 | .99 | .23 |
| **0916** | 24 | 31 | 6 | 34 | 1.48 | 8.09 | **.004** | .13 |
| **1016** | 54 | 1 | 31 | 9 | 2.75 | 6.52 | **.01** | .23 |
| **1116** | 25 | 30 | 3 | 37 | 2.33 | 12.52 | **.000** | .25 |
| 1216 | 13 | 42 | 0 | 40 | 20.03 | 0.00 | .99 | .28 |
| 1316 | 3 | 52 | 0 | 40 | 18.35 | 0.00 | NA | .14 |
| **1416** | 35 | 20 | 5 | 35 | 2.51 | 20.44 | **.000** | .33 |
| **1516** | 47 | 8 | 12 | 28 | 2.62 | 25.83 | **.000** | .39 |

Note: P value in **bold** reflect significant results **(P<.05)**. NA = Not Available.

***Analysis 2e: Effect of imageability on spelling accuracy.*** Results on Table 13 show that imageability is not statistically a significant predictor for spelling accuracy for almost all the participants. Only one participant (0716) had significant result.

Table 13

*Imageability as predictor to spelling accuracy*

| Case | Concrete 15 | | Abstract 15 | | B | Wald | P | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| | Correct | Error | Correct | Error | | | | |
| 0116 | 10 | 5 | 10 | 5 | 1.39 | 3.20 | .07 | .14 |
| 0216 | 7 | 8 | 6 | 9 | 0.27 | 0.14 | .71 | .01 |
| 0316 | 1 | 14 | 0 | 15 | 18.56 | 0.00 | .99 | 1.83 |
| 0416 | 15 | 0 | 15 | 0 | - | - | NA | - |
| 0516 | 13 | 2 | 14 | 1 | -0.77 | 0.36 | .55 | .03 |
| 0616 | 4 | 11 | 2 | 13 | 0.86 | 0.81 | .37 | .04 |
| **0716** | 13 | 2 | 6 | 9 | 2.28 | 6.07 | **.01** | .30 |
| 0816 | 3 | 12 | 4 | 11 | -0.38 | 0.19 | .68 | .01 |
| 0916 | 8 | 7 | 12 | 3 | -1.25 | 2.29 | .13 | .11 |
| 1016 | 13 | 2 | 14 | 1 | -0.77 | 0.36 | .55 | .03 |
| 1116 | 5 | 10 | 6 | 9 | -0.29 | 0.14 | .71 | .01 |
| 1216 | 9 | 6 | 5 | 10 | 1.09 | 2.09 | .15 | .09 |
| 1316 | 0 | 15 | 0 | 15 | - | - | NA | - |
| 1416 | 9 | 6 | 14 | 1 | -2.23 | 3.69 | .054 | .23 |
| 1516 | 15 | 0 | 13 | 2 | 19.33 | 0.00 | .99 | .24 |

Note: P value in **bold** reflect significant results **(P<.05)**. NA = Not Available.

***Analysis 2f: Effect of derivational morphology on spelling accuracy.*** An influence of word length on spelling is seen as one of the variables that affect spelling accuracy (Table 12). In Arabic, morphology is correlated with word length (i.e. simple morphological words has less letters and complex morphological words has more letters). Therefore, a significant affect of complex morphological words on spelling accuracy is predicted as shown in Table 14 for almost all participants. Some participants had either correct responses or incorrect responses and a binary logistic regression was not computed.

Table 14

*Derivational morphology as predictor to spelling accuracy*

| Case | Simple 30 | | Complex 20 | | B | Wald | P | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| | Correct | Error | Correct | Error | | | | |
| **0116** | 17 | 13 | 4 | 16 | 1.66 | 6.11 | **.01** | .18 |
| **0216** | 25 | 5 | 8 | 12 | 2.02 | 9.06 | **.003** | .25 |
| 0316 | 0 | 30 | 0 | 20 | - | - | NA | - |
| 0416 | 30 | 0 | 20 | 0 | - | - | NA | - |
| 0516 | NA | NA | NA | NA | - | - | NA | - |
| 0616 | 4 | 26 | 0 | 20 | 19.33 | 0.00 | .99 | .19 |
| **0716** | 26 | 4 | 5 | 15 | 2.97 | 15.89 | **.000** | .46 |
| 0816 | 10 | 20 | 0 | 20 | 20.51 | 0.00 | .99 | .33 |
| **0916** | 19 | 11 | 2 | 18 | 3.64 | 11.00 | **.001** | .48 |
| 1016 | 30 | 0 | 16 | 4 | 19.82 | 0.00 | .99 | .34 |
| **1116** | 12 | 18 | 2 | 18 | 1.79 | 4.62 | **.03** | .16 |
| **1216** | 13 | 17 | 1 | 19 | 2.68 | 6.03 | **.01** | .27 |
| 1316 | 6 | 24 | 0 | 20 | 19.82 | 0.00 | .99 | .24 |
| 1416 | - | - | - | - | - | - | NA | - |
| **1516** | 25 | 5 | 10 | 10 | 1.61 | 5.89 | **.02** | .17 |

Note: P value in **bold** reflect significant results **(P<.05)**. NA = Not Available.

#### ***Analysis 2g: Effect of inflectional morphology on spelling accuracy.***

Inflectional morphology showed less effect on spelling accuracy compared to the derivational morphology effect seen on Table 14. Inflectional morphology was statistically significant predictor (p < .05) for only 4 participants as seen in Table 15.

Table 15

*Inflectional Morphology as predictor to spelling accuracy*

| Case | Verbs 24 | | Nouns 16 | | B | Wald | P | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| | Correct | Error | Correct | Error | | | | |
| 0116 | 0 | 24 | 5 | 11 | -20.41 | 0.00 | .99 | .43 |
| 0216 | 15 | 9 | 10 | 6 | 1.02 | 2.35 | .13 | .08 |
| 0316 | 0 | 24 | 0 | 16 | - | - | NA | 1 |
| 0416 | 22 | 2 | 16 | 0 | -18.81 | 0.00 | .99 | .16 |
| 0516 | NA | NA | NA | NA | | NA | | |
| **0616** | 2 | 22 | 7 | 9 | -2.15 | 5.76 | **.02** | .24 |
| 0716 | 7 | 17 | 7 | 9 | -0.64 | 0.89 | .35 | .03 |
| 0816 | 1 | 23 | 4 | 12 | -2.04 | 3.01 | .08 | .17 |
| **0916** | 6 | 18 | 2 | 14 | -3.05 | 11.68 | **.001** | .45 |
| 1016 | 22 | 2 | 14 | 2 | 0.45 | 0.18 | .67 | .01 |
| **1116** | 3 | 21 | 8 | 8 | -1.95 | 6.00 | **.01** | .23 |
| 1216 | 4 | 20 | 3 | 13 | -0.14 | 0.03 | .87 | .00 |
| 1316 | 2 | 22 | 2 | 14 | -0.45 | 0.18 | .67 | .01 |
| 1416 | - | - | - | - | - | - | NA | - |
| **1516** | 8 | 16 | 12 | 4 | -1.79 | 6.16 | **.01** | .21 |

Note: P value in **bold** reflect significant results **(P<.05)**. NA = Not Available.

In summary, Table 16 provides the rank of the independent variables that have the most and least number of participants who had statistically significant effect on spelling performance. As shown, word length is the most variable that has significant prediction on spelling accuracy (n=8). In contrast, imageability is the least variable that has significant prediction on spelling accuracy (n=1).

Table 16

*Descriptive summary of binary logistic regression*

| **Rank** | **Predictor** | **Number of participants with significant results** | **P** |
|---|---|---|---|
| **1** | Word Length | 8 | < .05 |
| **2** | Derivational Morphology | 7 | < .05 |
| **3** | Lexicality<br>Word Frequency<br>Inflectional Morphology | 4 | < .05 |
| **4** | Regularity | 3 | < .05 |
| **5** | Imageability | 1 | < .05 |

**3- Spelling Errors.** Various types of spelling errors were observed while analyzing the performance of each participant. The errors can be grouped into two categories: 1) word errors such as substitutions; omissions (deletions); movement; addition (insertion); compound, and 2) lexical errors such as morphological; semantic; visual; phonological; regularization; and other errors resulted in real words or non-words (see Appendix 4 for examples). In the course of the analysis, spelling errors were computed to help localize the deficit in the spelling model for each participant. From a total of 290 words (for each participants) the errors were classified based on different characteristics (see Appendix for definition and examples). Tables 17-18 provide descriptive data on the number and percentages of error types for each participant.

Table 17

*Descriptive data of spelling error types for each participant*

| Error Type | Case No. (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **0116** | **0216** | **0316** | **0416** | **0516** | **0616** | **0716** |
| **Substitutions** | | | | | | | |
| 1 letter | 2 (2) | 8 (4) | 1 (0.3) | 0 | 10(20) | 12 (5) | 14(14) |
| +1 letter | 0 | 0 | 0 | 0 | 1 (2) | 8 (3) | 1 (1) |
| **Omission** | | | | | | | |
| 1 letter | **47(36)** | 12 (6) | 2 (0.7) | 1(12) | **15(29)** | 6 (2) | **25 (25)** |
| +1 letter | 16(12) | 11 (6) | 0 | 0 | 1 (2) | 6 (2) | 7 (7) |
| **Addition** | | | | | | | |
| 1 letter | 10 (8) | 2 (1) | 2 (.07) | **3(38)** | 7 (14) | 14 (6) | 11 (10) |
| +1 letter | 0 | 0 | 1 (0.3) | 0 | 0 | 7 (3) | 0 |
| **Movement** | 7 (5) | 2 (1) | 2 (.07) | 0 | 4 (8) | 4 (1) | 6 (6) |
| **Compound** | 11 (8) | 5 (2) | 2 (.07) | 1(12) | 3 (6) | 18 (7) | 7 (7) |
| **Phonological** | 6 (5) | 1 (1) | 0 | **3(38)** | 2(4) | 11 (5) | 3 (3) |
| **Morphological** | 13(10) | 21 (10) | 5 (2) | 0 | 3 (6) | 5 (2) | 1 (1) |
| **Regularization** | 0 | 0 | 0 | 0 | 0 | 0 | 12 (12) |
| **Visual** | 5 (4) | 1 (1) | 0 | 0 | 1 (2) | 3 (1) | 2 (2) |
| **Semantic** | 0 | 13 (6) | 4 (1) | 0 | 1 (2) | 2 (1) | 3 (3) |
| **Other** | 2 (2) | **92 (44)** | **245(88)** | 0 | 3 (6) | **162(64)** | 9 (9) |
| **No response** | 10 (8) | 40 (19) | 14 (5) | 0 | 0 | 0 | 0 |
| **Total** | 129 | 208 | 278 | 8 | 51 | 252 | 101 |

Table 18

*Descriptive data of spelling error types for each participant*

| **Error Type** | **Case No. (%)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **0816** | **0916** | **1016** | **1116** | **1216** | **1316** | **1416** | **1516** |
| **Substitutions** | | | | | | | | |
| 1 letter | 19(8) | 15(10) | 5(15) | 15(10) | 18(10) | 5 (2) | 18(16) | 1 (1) |
| +1 letter | 0 | 1 (1) | 0 | 1 (1) | 1 (0.5) | 1(0.5) | 1 (1) | 0 |
| **Omission** | | | | | | | | |
| 1 letter | 10(4) | **40(26)** | 7(20) | **40(26)** | 38(20) | 22 (8) | **40(36)** | **23(34)** |
| +1 letter | 13(6) | 8 (5) | 0 | 9 (6) | 12 (6) | 35(12) | 24(22) | 5 (7) |
| **Addition** | | | | | | | | |
| 1 letter | 5 (3) | 8 (5) | 2 (6) | 16(10) | 13 (7) | 0 | 2 (2) | 4 (6) |
| +1 letter | 0 | 1 (1) | 0 | 1 (1) | 0 | 0 | 0 | 1 (1) |
| **Movement** | 3 (1) | 5 (3) | 0 | 7 (5) | 2 (1) | 1 (0.5) | 2 (2) | 4 (6) |
| **Compound** | 11(5) | 13 (8) | 0 | 17(11) | 9 (5) | 6 (2) | 6 (5) | 5 (7) |
| **Phonological** | 3 (1) | 7 (4) | 2 (6) | 4 (4) | 4 (2) | 0 | 0 | 2 (3) |
| **Morphological** | 12(5) | 11 (7) | 0 | 29(19) | 10 (5) | 0 | 0 | 9 (13) |
| **Regularization** | 3 (1) | 29(19) | **18(53)** | 7 (5) | 3 (2) | 0 | 1 (1) | 2 (3) |
| **Visual** | 0 | 2 (1) | 0 | 3 (2) | 0 | 0 | 0 | 1 (1) |
| **Semantic** | 8 (3) | 3 (2) | 0 | 3 (2) | 1 (0.5) | 0 | 0 | 1 (1) |
| **Other** | **33(15)** | 13 (8) | 0 | 13 (8) | **61(32)** | **75(26)** | 9 (8) | 5 (7) |
| **No response** | 111 (48) | 0 | 0 | 0 | 17 (9) | 133 (47) | 8 (7) | 7 (10) |
| **Total** | 231 | 156 | 34 | 154 | 189 | 278 | 111 | 70 |

**4- Localizing the deficits in the spelling system.** For each of the individuals we attempted to identify the locus of the deficit in the spelling system based on the error types and the qualitative characteristics of the spelling performance using the Dual-Route Model. Results in Table 4 showed that all subjects were unable to read non-words and this indicate impaired sublexical route with impaired phonology-orthography conversion mechanism. The results presented in Table 19 show the localization of the deficit in the lexical route components.

The results presented in Table 19 show that seven subjects (0116, 0516, 0716, 0916, 1116, 1416, 1516) exhibit the typical pattern associated with impairment affecting orthographic working memory (Graphemic Buffer GB). These seven individuals exhibit no effect of frequency on spelling accuracy and a significant effect of letter length. In addition their error types consists mainly of omissions or substitutions of letters.

Table 19 also shows three subjects (0216- 0816- 1216) exhibit pattern associated with impairment affecting the orthographic out-put lexicon with characteristics of better performance on high-frequency words than low-frequency words (0816- 1216) and more lexical errors. However, they also had significant difference in performance based on length.

Table 19

*Localizing the spelling deficits in the lexical route*

| Graphemic Buffer | Orthographic output lexicon | Undifferentiated | No Dysgraphia |
|---|---|---|---|
| 0116 | 0216 | 0316 | 0416 |
| 0516 | 0816 | 0616 | |
| 0716 | 1216 | 1016 | |
| 0916 | | 1316 | |
| 1116 | | | |
| 1416 | | | |
| 1516 | | | |

Note: All participants had problems in sub-lexical route with impaired spelling of non-words

Analyzing the qualitative characteristics and types of the spelling errors also helped identifying the types of acquired dysgraphia seen in Arabic individual with Aphasia who participated in this study. Table 20 provides the types of acquired dysgraphia for each participant.  Three subjects (20%) showed the characteristics of phonological dysgraphia with impaired ability to write non-words and preserved ability to write real words. Four subjects (27%) exhibit the characteristics of mixed dysgraphia with impaired sub-lexical route and deficit at the level of orthographic output lexicon with error types consisted of regularization (1016) and lexical errors with better performance on high frequency words. The analysis also revealed that seven subjects (46%) exhibit the characteristics of graphemic buffer impairment with the effect of word length and word errors that consisted mainly of omissions of letters. One subject (7%) had no writing impairment.

Table 20

*Types of Dysgraphia*

| Phonological Dysgraphia | Mixed Dysgraphia | Graphemic Buffer Dysgraphia | Un-differentiated | No Dysgraphia |
|---|---|---|---|---|
| 0316 | 0216 | 0116 | - | 0416 |
| 0616 | 0816 | 0516 | | |
| 1316 | 1016 | 0716 | | |
| | 1216 | 0916 | | |
| | | 1116 | | |
| | | 1416 | | |
| | | 1516 | | |

**5- Serial Position in word.** In this section, we analyze accuracy as a function of the position of letters in a word. Impairment affecting the graphemic buffer has been typically associated with a bow-shaped accuracy function, such that individuals perform better at letters at the beginning and end of words than they do on medial letters.

To compare words of different lengths, normalized letter positions of words was used following the procedure outlined in Machtynger and Shallice (2009; an update of the Wing and Baddeley, 1980, scheme). This analysis included subjects that had deficit localized at the level of the Graphemic buffer (Table 19).

Figure 7 below shows the serial position curves for the seven subjects. All subjects had more errors in the middle of the words (i.e., second or third letter position in a word) compared to the initial or final letters of the word. However, bow-shaped serial position curve was clearly revealing only in case 1116.

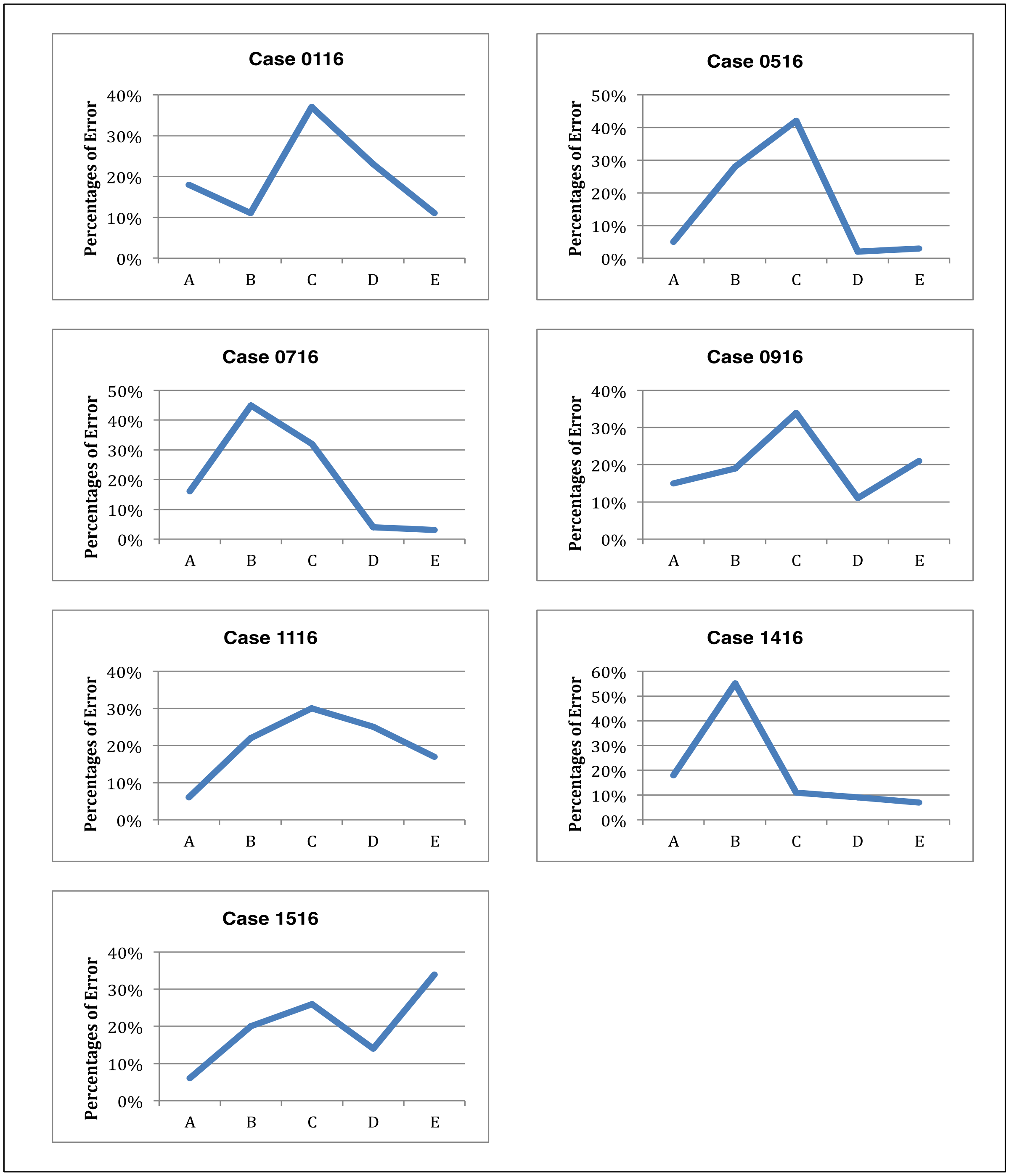


*Figure 7.* Standardized letter position

**Section Three: Reading Aloud**

Reading aloud performance analysis is the focus of this section. Raw scores and error patterns of each participant were used independently in the statistical analysis. Chi-square of difference and logistic regression were implemented followed by the localization of deficit and the qualitative pattern of reading-aloud errors.

**6- Chi-square of difference.** Similar to the writing to dictation task, the chi square statistics was performed for reading aloud to see if there is a difference in performance between two levels in each independent variable. Before we compute the chi-square test, several assumptions were tested and met: Nominal level variables, random samples, the independence of data (each entity contributes to only one cell of the contingency table so the chi-square test cannot be performed on a repeated-measure design), and the expected frequencies were greater than 5 as the chi-square shows considered 2x2 tables.

***Analysis 6a: Performance on lexicality list.*** Table 21 shows that all subjects were unable to read non-words and there was a statistically significant difference ($p < .05$) on reading aloud words compared to non-words. This finding is similar to the result shown in Table 4 for writing to dictation.

Some subjects such as 0416, 1216 scored better than others on reading non-words, however all subjects, except 1016, failed to read non-words.

Table 21

*Lexicality list, contrasting words and non-words*

| Case | Words 40 | | Non-Words 32 | | Analysis |
|---|---|---|---|---|---|
| | Correct | % | Correct | % | |
| **0116** | 40 | 100 | 15 | 47 | **$X^2 = 27.82$, df (1), p < .05** |
| **0216** | 23 | 58 | 2 | 6 | **$X^2 = 20.60$, df (1), p < .05** |
| **0316** | 28 | 70 | 0 | 0 | **$X^2 = 36.66$, df (1), p < .05** |
| **0416** | 38 | 76 | 23 | 72 | **$X^2 = 36.66$, df (1), p < .05** |
| **0516** | 37 | 93 | 6 | 19 | **$X^2 = 40.12$, df (1), p < .05** |
| **0616** | 9 | 23 | 0 | 0 | **$X^2 = 8.23$, df (1), p < .05** |
| **0716** | 40 | 100 | 17 | 53 | **$X^2 = 23.68$, df (1), p < .05** |
| **0816** | 27 | 68 | 0 | 0 | **$X^2 = 34.56$, df (1), p < .05** |
| **0916** | 38 | 95 | 13 | 41 | **$X^2 = 25.44$, df (1), p < .05** |
| **1016** | 40 | 100 | 30 | 99 | NA |
| **1116** | 23 | 58 | 6 | 19 | **$X^2 = 11.09$, df (1), p < .05** |
| **1216** | 39 | 98 | 14 | 43 | **$X^2 = 26.44$, df (1), p < .05** |
| **1316** | 38 | 95 | 2 | 6 | **$X^2 = 56.71$, df (1), p < .05** |
| **1416** | 40 | 100 | 12 | 38 | **$X^2 = 34.62$, df (1), p < .05** |
| **1516** | 22 | 55 | 0 | 0 | **$X^2 = 25.34$, df (1), p < .05** |

Note: Significant differences are denoted in **bold (P<.05)**. Statistical tests were chi-square, except for comparisons with cell values smaller than 5, which were computed with Fisher’s Exact. NA = Not Available.

***Analysis 6b: Performance on word frequency list.*** When excluding subject 0416,and 1016 who scored 100% accuracy, the overall results in Table 22 show no statistical differences in all subjects when contrasting high and low frequency words.

Table 22

*Word Frequency list, contrasting high frequency and low frequency words*

| Case | High Frequency 95 | | Low Frequency 90 | | Analysis |
|---|---|---|---|---|---|
| | Correct | % | Correct | % | |
| 0116 | 81 | 85 | 74 | 82 | $X^2$ = .32, df (1), p = .58 |
| 0216 | 41 | 43 | 32 | 35 | $X^2$ = 1.12, df (1), p = .29 |
| 0316 | 40 | 42 | 35 | 39 | $X^2$ = .19, df (1), p = .66 |
| 0416 | 94 | 99 | 87 | 97 | NA |
| 0516 | 42/45 | 93 | 38/45 | 84 | $X^2$ = 1.80, df (1), p = .18 |
| 0616 | 18 | 19 | 11 | 12 | $X^2$ = 1.58, df (1), p = .21 |
| 0716 | 92 | 97 | 86 | 96 | Fisher's Exact, p = .72 |
| 0816 | 51 | 54 | 39 | 43 | $X^2$ = 1.98, df (1), p = .16 |
| 0916 | 84 | 88 | 81 | 90 | $X^2$ = .12, df (1), p = .73 |
| 1016 | 93 | 98 | 89 | 99 | NA |
| 1116 | 65 | 68 | 54 | 60 | $X^2$ = 1.43, df (1), p = .23 |
| 1216 | 80 | 84 | 72 | 80 | $X^2$ = .56, df (1), p = .46 |
| 1316 | 75 | 79 | 70 | 78 | $X^2$ = .04, df (1), p = .85 |
| 1416 | 89 | 94 | 88 | 98 | Fisher's Exact, p = .28 |
| 1516 | 40 | 42 | 42 | 47 | $X^2$ = .39, df (1), p = .53 |

Note: Significant differences are denoted in **bold (P<.05)**. Statistical tests were chi-square, except for comparisons with cell values smaller than 5, which were computed with Fisher's Exact. NA = Not Available.

***Analysis 6c: Performance on regularity list.*** Results seen in Table 23 show that 7 subjects had statistically significant difference in reading aloud vowelized and non-vowelized words, with later being higher. Three subjects 0416, 0516, and 1016 had correct performance, and the remaining five subjects showed no significant difference.

Table 23

*Regularity list, contrasting vowelized and un-vowelized words*

| Case | Vowelized 30 | | Un-vowelized 30 | | Analysis |
|---|---|---|---|---|---|
| | Correct | % | Correct | % | |
| 0116 | 23 | 77 | 28 | 93 | Fisher's Exact, p = .15 |
| **0216** | 10 | 33 | 18 | 60 | **$X^2$ = 4.29, df (1), p < .05** |
| **0316** | 7 | 23 | 16 | 53 | **$X^2$ = 5.71, df (1), p < .05** |
| 0416 | 29 | 99 | 30 | 100 | NA |
| 0516 | 26 | 87 | 30 | 100 | NA |
| 0616 | 5 | 17 | 8 | 27 | $X^2$ = .88, df (1), p = .35 |
| **0716** | 23 | 77 | 30 | 100 | **Fisher's Exact, p < .05** |
| **0816** | 8 | 27 | 17 | 57 | **$X^2$ = 5.55, df (1), P< .05** |
| 0916 | 23 | 77 | 27 | 90 | $X^2$ = 1.92, df (1), p = .17 |
| 1016 | 30 | 100 | 30 | 100 | NA |
| 1116 | 22 | 73 | 26 | 87 | $X^2$ = 1.67, df (1), p = .19 |
| **1216** | 14 | 47 | 23 | 77 | **$X^2$ = 5.71, df (1), p < .05** |
| **1316** | 15 | 50 | 29 | 97 | **$X^2$ = 16.71, df (1), p < .05** |
| 1416 | 25 | 83 | 30 | 100 | Fisher's Exact, p = .052 |
| **1516** | 7 | 23 | 19 | 63 | **$X^2$ = 9.77, df (1), p < .05** |

Note: Significant differences are denoted in **bold (P<.05)**. Statistical tests were chi-square, except for comparisons with cell values smaller than 5, which were computed with Fisher's Exact. NA = Not Available.

***Analysis 6d: Performance on word length list.*** From Table 24, If we exclude subject 0416 and 1016 for 100% performance and subject 0616 for incorrect performance and subject 0516 for unavailability of data, the remaining subjects (n=10) had statistically significant difference ($p < .05$) in reading aloud short words compared to long words.

Table 24

*Word Length, contrasting short words (SW) and long words (LW)*

| Case | SW 55 | | LW 40 | | Analysis |
|---|---|---|---|---|---|
| | Correct | % | Correct | % | |
| **0116** | 49 | 89 | 16 | 40 | **$X^2 = 31.18$, df (1), $p < .05$** |
| **0216** | 26 | 47 | 11 | 28 | **$X^2 = 5.53$, df (1), $p < .05$** |
| **0316** | 25 | 45 | 2 | 5 | **$X^2 = 21.12$, df (1), $p < .05$** |
| 0416 | 55 | 100 | 38 | 95 | NA |
| 0516 | - | - | - | - | NA |
| 0616 | 4 | 7 | 0 | 0 | Fisher's Exact, $p = .13$ |
| **0716** | 55 | 100 | 36 | 90 | **Fisher's Exact, $p < .05$** |
| **0816** | 31 | 56 | 9 | 23 | **$X^2 = 13.64$, df (1), $p < .05$** |
| **0916** | 49 | 89 | 31 | 78 | **$X^2 = 6.31$, df (1), $p < .05$** |
| 1016 | 55 | 100 | 37 | 93 | NA |
| **1116** | 37 | 67 | 7 | 18 | **$X^2 = 26.87$, df (1), $p < .05$** |
| **1216** | 46 | 84 | 18 | 45 | **$X^2 = 20.46$, df (1), $p < .05$** |
| **1316** | 49 | 89 | 23 | 58 | **$X^2 = 17.71$, df (1), $p < .05$** |
| **1416** | 54 | 98 | 33 | 83 | **$X^2 = 13.51$, df (1), $p < .05$** |
| **1516** | 25 | 46 | 0 | 0 | **$X^2 = 27.27$, df (1), $p < .05$** |

Note: Significant differences are denoted in **bold ($P<.05$)**. Statistical tests were chi-square, except for comparisons with cell values smaller than 5, which were computed with Fisher's Exact. NA = Not Available.

***Analysis 6e: Performance on morphological list.*** Similar to writing to dictation, in the morphological list analysis, words were grouped into two categories: simple words that have short words configuration of 3-4-5-letters (SSW n=30), and complex words that has longer words of 6 and 7 letters (CLW n=20). Table 25 shows the results of six subjects, where they all had a statistically significant difference in spelling simple-short words compared to complex-long words.

Table 25

*Morphological list, contrasting simple-short words (SSW) and complex-long words (CLW)*

| Case | SSW 30 | | CLW 20 | | Analysis |
|---|---|---|---|---|---|
| | Correct | % | Correct | % | |
| 0116 | 23 | 77 | 17 | 85 | $X^2 = .52$, df (1), p = .47 |
| **0216** | 21 | 70 | 7 | 35 | **$X^2 = 5.97$, df (1), p < .05** |
| 0316 | 5 | 17 | 0 | 0 | Fisher's Exact, p = .07 |
| 0416 | 30 | 100 | 20 | 100 | NA |
| 0516 | - | - | - | - | NA |
| 0616 | 6 | 20 | 0 | 0 | Fisher's Exact, p = .07 |
| 0716 | 27 | 90 | 18 | 90 | NA |
| **0816** | 14 | 47 | 0 | 0 | **$X^2 = 12.96$, df (1), p < .05** |
| 0916 | 30 | 100 | 20 | 100 | NA |
| 1016 | 30 | 100 | 20 | 100 | NA |
| **1116** | 23 | 77 | 7 | 35 | **$X^2 = 8.68$, df (1), P< .05** |
| **1216** | 23 | 77 | 14 | 47 | **$X^2 = 5.71$, df (1), p < .05** |
| **1316** | 19 | 63 | 5 | 25 | **$X^2 = 7.07$, df (1), p < .05** |
| 1416 | 30 | 100 | 20 | 100 | NA |
| **1516** | 16 | 53 | 0 | 0 | **$X^2 = 15.69$,df (1), p < .05** |

Note: Significant differences are denoted in **bold (P<.05)**. Statistical tests were chi-square, except for comparisons with cell values smaller than 5, which were computed with Fisher's Exact. NA = Not Available.

In summary, the chi-square of difference analysis showed that the same three independent variables: lexicallty, word length and derivative morphology seen in writing to dictation, in addition to regularity, had an overall significant difference in reading aloud performance as well.

**7- Logistic regression.** Binary logistic regression analysis was applied, similarly to writing to dictation, to the profile of each participant to study the effect of different variables that might influence reading aloud accuracy. The dependent variable for each stimulus was either 0 (error) or 1 (correct). The independent variables were all nominal with two categories: 1) Word frequency (high- low), 2) Regularity (vowelized-unvowelized), 3) Imageability (concrete- Abstract), 4) Word length (short- long), 5) Derivative morphology (simple- complex), and 6) inflectional morphology (verbs-nouns). Table 33 provides a descriptive summary for the binary logistic regressions in reading aloud task.

***Analysis 7a: Effect of lexicality on reading aloud accuracy.*** Table 26 show that lexicality has statistically significant predictive effect on reading aloud accuracy for seven subjects (0216, 0416, 0516, 0916, 1116, 1216, 1316).

Table 26

*Word frequency as predictor to reading aloud accuracy*

| Case | Words 40 | | Non-words 32 | | B | Wald | P | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| | Correct | Error | Correct | Error | | | | |
| 0116 | 40 | 0 | 15 | 17 | 21.33 | 0.00 | .99 | .57 |
| **0216** | 23 | 17 | 2 | 30 | 3.01 | 14.26 | **.000** | .38 |
| 0316 | 28 | 12 | 0 | 32 | 22.05 | 0.00 | .99 | .65 |
| **0416** | 38 | 2 | 23 | 9 | 2.01 | 5.91 | **.02** | .18 |
| **0516** | 37 | 3 | 6 | 26 | 3.98 | 27.99 | **.000** | .63 |
| 0616 | 9 | 31 | 0 | 32 | 19.97 | 0.00 | .99 | .28 |
| 0716 | 40 | 0 | 17 | 15 | 21.08 | 0.00 | .99 | .52 |
| 0816 | 27 | 13 | 0 | 32 | 21.93 | 0.00 | .99 | .63 |
| **0916** | 38 | 2 | 13 | 19 | 3.32 | 16.85 | **.000** | .46 |
| 1016 | 40 | 0 | 30 | 2 | - | - | NA | - |
| **1116** | 23 | 7 | 6 | 26 | 1.77 | 10.18 | **.000** | .20 |
| **1216** | 39 | 1 | 14 | 18 | 3.41 | 10.10 | **.001** | .39 |
| **1316** | 38 | 2 | 2 | 30 | 5.65 | 30.15 | **.000** | .82 |
| 1416 | 40 | 0 | 12 | 20 | 21.71 | 0.00 | .99 | .65 |
| 1516 | 22 | 18 | 0 | 32 | 21.40 | 0.00 | .99 | .53 |

Note: P value in **bold** reflect significant results **(P<.05)**. NA = Not Available.

***Analysis 7b: Effect of word Frequency on reading aloud accuracy.*** Table 27 show that word frequency has no statistically significant predictive effect on reading aloud accuracy for all subjects (n= 15).

Table 27

*Word frequency as predictor to reading aloud accuracy*

| Case | High Frequency 45 | | Low Frequency 45 | | B | Wald | P | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| | Correct | Error | Correct | Error | | | | |
| 0116 | 45 | 0 | 45 | 0 | - | - | NA | - |
| 0216 | 24 | 21 | 21 | 24 | -0.27 | 0.39 | .53 | .01 |
| 0316 | 25 | 20 | 23 | 22 | -0.18 | 0.18 | .67 | .00 |
| 0416 | 45 | 0 | 43 | 2 | -18.14 | 0.00 | .99 | .16 |
| 0516 | 42 | 3 | 37 | 8 | -1.11 | 2.41 | .12 | .06 |
| 0616 | 14 | 31 | 10 | 35 | -0.46 | 0.90 | .34 | .02 |
| 0716 | 44 | 1 | 43 | 2 | -0.72 | 0.33 | .57 | .02 |
| 0816 | 31 | 14 | 25 | 20 | -0.57 | 1.69 | .19 | .03 |
| 0916 | 42 | 3 | 42 | 3 | - | - | NA | - |
| 1016 | 44 | 1 | 45 | 0 | 17.42 | 0.00 | .99 | .13 |
| 1116 | 41 | 4 | 34 | 11 | -1.19 | 3.64 | .06 | .07 |
| 1216 | 44 | 1 | 44 | 1 | - | - | NA | - |
| 1316 | 35 | 10 | 38 | 7 | 0.62 | 1.25 | .27 | .02 |
| 1416 | 45 | 0 | 45 | 0 | - | - | NA | - |
| 1516 | 26 | 19 | 31 | 14 | 0.48 | 1.19 | .28 | .02 |

Note: P value in **bold** reflect significant results **(P<.05)**. NA = Not Available.

***Analysis 7c: Effect of regularity on reading aloud accuracy.*** When binary logistic regression was computed on the regularity list, results were statistically not significant for 10 participants. As seen in Table 28, regularity variable was statistically significant predictor ($p < .05$) in reading aloud accuracy for subjects 0216, 0316, 1216, 1316, and 1516.

Table 28

*Regularity as predictor to reading aloud accuracy*

| Case | Vowelized 30 | | Un-vowelized 30 | | B | Wald | P | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| | Correct | Error | Correct | Error | | | | |
| 0116 | 23 | 7 | 28 | 2 | -1.45 | 2.91 | .09 | .09 |
| **0216** | 10 | 20 | 18 | 12 | -1.09 | 4.18 | **.04** | .09 |
| **0316** | 7 | 23 | 16 | 14 | -1.32 | 5.47 | **.02** | .13 |
| 0416 | 29 | 1 | 30 | 0 | - | - | NA | - |
| 0516 | 26 | 4 | 30 | 0 | - | - | NA | - |
| 0616 | 5 | 25 | 8 | 22 | -0.59 | 0.87 | .35 | .02 |
| 0716 | 23 | 7 | 30 | 0 | -20.01 | 0.00 | .99 | .32 |
| 0816 | 8 | 22 | 17 | 13 | -0.14 | 0.07 | .79 | .00 |
| 0916 | 23 | 7 | 27 | 3 | -1.01 | 1.82 | .18 | .05 |
| 1016 | 30 | 0 | 30 | 0 | - | - | NA | - |
| 1116 | 22 | 8 | 26 | 4 | -0.86 | 1.61 | .20 | .04 |
| **1216** | 14 | 16 | 23 | 7 | -1.32 | 5.47 | **.02** | .13 |
| **1316** | 15 | 15 | 29 | 1 | -3.37 | 9.71 | **.002** | .40 |
| 1416 | 25 | 5 | 30 | 0 | - | - | NA | - |
| **1516** | 7 | 23 | 19 | 11 | -1.74 | 9.14 | **.003** | .21 |

Note: P value in **bold** reflect significant results **(P<.05)**. NA = Not Available.

***Analysis 7d: Effect of word length on reading aloud accuracy.*** Table 29 shows that word length was statistically significant predictor ($p < .05$) in seven subjects. The analysis excluded six subjects: subject 0416, 0716 and 1016 for almost 100% performance, subjects 0616 and 1516 for incorrect performance, and subject 0516 for unavailability of the data.

Table 29

*Word Length as predictor to reading aloud accuracy*

| Case | SW 55 | | LW 40 | | B | Wald | P | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| | Correct | Error | Correct | Error | | | | |
| **0116** | 49 | 6 | 16 | 24 | 2.51 | 21.56 | **.000** | .34 |
| 0216 | 26 | 29 | 11 | 29 | 0.86 | 3.73 | .053 | .05 |
| **0316** | 25 | 30 | 2 | 38 | 2.76 | 12.72 | **.000** | .29 |
| 0416 | 55 | 0 | 38 | 2 | - | - | NA | - |
| 0516 | - | - | - | - | - | - | - | - |
| 0616 | 4 | 51 | 0 | 40 | - | - | NA | - |
| 0716 | 55 | 0 | 36 | 4 | - | - | NA | - |
| **0816** | 31 | 24 | 9 | 31 | 1.49 | 10.25 | **.001** | .15 |
| 0916 | 49 | 6 | 31 | 9 | 0.86 | 2.26 | .13 | .04 |
| 1016 | 55 | 0 | 37 | 3 | - | - | NA | - |
| **1116** | 37 | 18 | 7 | 33 | 2.27 | 20.17 | **.000** | .30 |
| **1216** | 46 | 9 | 18 | 22 | 1.33 | 7.51 | **.01** | .12 |
| **1316** | 49 | 6 | 23 | 17 | 1.79 | 11.17 | **.00** | .19 |
| **1416** | 54 | 1 | 33 | 7 | 2.44 | 4.99 | **.03** | .18 |
| 1516 | 25 | 30 | 0 | 40 | - | - | NA | - |

Note: P value in **bold** reflect significant results **(P<.05)**. NA = Not Available.

***Analysis 7e: Effect of imageability on reading aloud accuracy.*** Results on Table 30 show that imageability is not statistically a significant predictor for reading aloud accuracy for almost all the participants. Only one participant (0816) had significant result ($p < .05$).

Table 30

*Imageability as predictor to reading aloud accuracy*

| Case | Concrete 15 | | Abstract 15 | | B | Wald | P | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| | Correct | Error | Correct | Error | | | | |
| 0116 | 15 | 0 | 15 | 0 | - | - | NA | - |
| 0216 | 11 | 4 | 7 | 8 | 1.15 | 2.15 | .14 | .09 |
| 0316 | 8 | 7 | 5 | 10 | 0.83 | 1.20 | 2.73 | .05 |
| 0416 | 15 | 0 | 15 | 0 | - | - | NA | - |
| 0516 | 15 | 0 | 14 | 1 | - | - | NA | - |
| 0616 | 4 | 11 | 4 | 11 | - | - | NA | - |
| 0716 | 15 | 0 | 15 | 0 | - | - | NA | - |
| **0816** | 13 | 2 | 5 | 10 | 2.57 | 7.50 | **.01** | .37 |
| 0916 | 13 | 2 | 14 | 1 | -0.77 | 0.36 | .55 | .03 |
| 1016 | 15 | 0 | 15 | 0 | - | - | NA | - |
| 1116 | 15 | 0 | 13 | 2 | - | - | NA | - |
| 1216 | 11 | 4 | 13 | 2 | -0.86 | 0.81 | .37 | .04 |
| 1316 | 10 | 5 | 13 | 2 | -1.18 | 1.54 | .21 | .08 |
| 1416 | 15 | 0 | 15 | 0 | - | - | NA | - |
| 1516 | 9 | 6 | 8 | 7 | 0.27 | 0.14 | .71 | .01 |

Note: P value in **bold** reflect significant results **(P<.05)**. NA = Not Available.

***Analysis 7f: Effect of derivational morphology on reading aloud accuracy.***

The data for the binary logistic analysis for the effect of derivational morphology on reading aloud was available for seven subjects only. Among these subjects, only two (0216, 1316) showed statistically significant effect of derivative morphology on reading aloud as seen in Table 31.

Table 31

*Derivational morphology as predictor to reading aloud accuracy*

| Case | Simple 30 | | Complex 20 | | B | Wald | P | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| | Correct | Error | Correct | Error | | | | |
| 0116 | 23 | 7 | 17 | 3 | -0.55 | 0.51 | .47 | .02 |
| **0216** | 21 | 9 | 7 | 13 | 1.47 | 5.68 | **.02** | .15 |
| 0316 | 5 | 25 | 0 | 20 | - | - | NA | - |
| 0416 | 30 | 0 | 20 | 0 | - | - | NA | - |
| 0516 | - | - | - | - | - | - | NA | - |
| 0616 | 6 | 24 | 0 | 20 | - | - | NA | - |
| 0716 | 27 | 3 | 18 | 2 | - | - | NA | - |
| 0816 | 14 | 16 | 0 | 20 | 21.07 | 0.00 | .99 | .43 |
| 0916 | 30 | 0 | 20 | 0 | - | - | NA | - |
| 1016 | 30 | 0 | 20 | 0 | - | - | NA | - |
| 1116 | 23 | 7 | 7 | 13 | 0.57 | 0.80 | .37 | .02 |
| 1216 | 23 | 7 | 14 | 6 | 0.34 | 0.28 | .59 | .01 |
| **1316** | 19 | 11 | 5 | 15 | 1.65 | 6.59 | **.01** | .18 |
| 1416 | 30 | 0 | 20 | 0 | - | - | NA | - |
| 1516 | 16 | 14 | 0 | 20 | 21.34 | 0.00 | .99 | .48 |

Note: P value in **bold** reflect significant results **(P<.05)**. NA = Not Available.

***Analysis 7g: Effect of inflectional morphology on reading aloud accuracy.***

Seven subjects were not included in this analysis as seen in Table 32. For the remaining subjects (n=7), inflectional morphology did not predict reading aloud accuracy. Only one subject (1316) had statistically significant results ($p < .05$).

Table 32

*Inflectional Morphology as predictor to reading aloud accuracy*

| Case | Verbs 24 | | Nouns 16 | | B | Wald | P | $R^2$ |
|---|---|---|---|---|---|---|---|---|
| | Correct | Error | Correct | Error | | | | |
| 0116 | 12 | 12 | 12 | 4 | -0.93 | 1.73 | .18 | .06 |
| 0216 | 13 | 11 | 13 | 3 | -1.29 | 2.92 | .09 | .11 |
| 0316 | 0 | 24 | 2 | 14 | - | - | NA | - |
| 0416 | 18 | 6 | 16 | 0 | - | - | NA | - |
| 0516 | - | - | - | - | - | - | NA | - |
| 0616 | 1 | 23 | 0 | 16 | - | - | NA | - |
| 0716 | 20 | 4 | 16 | 0 | - | - | NA | - |
| 0816 | 1 | 23 | 4 | 12 | -2.04 | 3.01 | .08 | .17 |
| 0916 | 16 | 8 | 15 | 1 | -2.02 | 3.24 | .07 | .17 |
| 1016 | 22 | 2 | 16 | 0 | - | - | NA | - |
| 1116 | 7 | 17 | 6 | 10 | -0.38 | 0.30 | .58 | .01 |
| 1216 | 11 | 13 | 9 | 7 | -0.42 | 0.42 | .52 | .01 |
| **1316** | 1 | 23 | 10 | 6 | -2.91 | 10.42 | **.00** | .42 |
| 1416 | 18 | 6 | 8 | 8 | 1.09 | 2.56 | .11 | .09 |
| 1516 | 0 | 24 | 4 | 12 | - | - | NA | - |

Note: P value in **bold** reflect significant results **(P<.05)**. NA = Not Available.

In summary, Table 33 provides the rank of the independent variables that have the most and least number of participants who had statistically significant effect reading aloud accuracy. As shown, lexicality and word length are the most variables that have significant prediction on reading aloud accuracy (n=7). Word length showed similar findings for spelling accuracy as shown in Table 16. In contrast, word frequency is the least variable that has significant prediction on reading aloud accuracy (n=0).

Table 33

*Descriptive summary of binary logistic regression in reading aloud*

| **Rank** | **Predictor** | **Number of participants with significant results** | **P** |
|---|---|---|---|
| **1** | Lexicality<br>Word Length | 7 | < .05 |
| **2** | Regularity | 5 | < .05 |
| **3** | Derivational Morphology | 2 | < .05 |
| **4** | Imageability<br>Inflectional Morphology | 1 | < .05 |
| **5** | Word Frequency | 0 | - |

**8- Reading aloud Errors.** In the course of the analysis, reading aloud errors were computed to help localize the deficit in the reading aloud model for each participant. From a total of 290 words (for each participants) the errors were classified based on different characteristics (see Appendix 2 for definition and examples). Tables 34-35 provide the descriptive data of the number and percentages of error types for each participant.

Table 34

*Descriptive data of reading aloud error types for each participant*

| **Error Type** | **Case No. (%)** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **0116** | **0216** | **0316** | **0416** | **0516** | **0616** | **0716** |
| **Phonological** | 6 (16) | 37 (24) | 27 (15) | **4 (80)** | **8 (43)** | 73(31) | 1 (7) |
| **Morphological** | **14 (38)** | 19 (13) | 24 (14) | - | 2 (10) | 5 (2) | **6 (43)** |
| **Regularization** | 1 (3) | - | - | - | 1 (5) | - | - |
| **Visual** | 5 (13) | 25(17) | 16 (9) | 1 (20) | 4 (21) | 15 (6) | **6 (43)** |
| **Semantic** | 1 (3) | 11 (7) | 9 (5) | - | - | 2 (1) | - |
| **Other** | 9 (24) | **55 (36)** | **42 (24)** | - | 3 (16) | **115(49)** | 1 (7) |
| **No response** | 1 (3) | 4 (3) | **58 (33)** | - | 1 (5) | 25(11) | - |
| **Total** | 37 | 151 | 177 | 5 | 19 | 235 | 14 |

Table 35

*Descriptive data of error types for each participant*

| Error Type | Case No. (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **0816** | **0916** | **1016** | **1116** | **1216** | **1316** | **1416** | **1516** |
| **Phonological** | 5 (4) | 2 (6) | - | 14 (17) | 5 (8) | 12 (18) | 3 (21) | **58 (38)** |
| **Morphological** | **18 (11)** | 9 (27) | **3 (80)** | 20 (24) | 13 (20) | **22 (32)** | 2 (14) | 10 (7) |
| **Regularization** | - | - | - | - | - | - | - | - |
| **Visual** | 11 (7) | **21 (64)** | 1 (20) | **32(38)** | **28 (44)** | 18 (26) | **9 (65)** | 6 (4) |
| **Semantic** | 15 (10) | 1 (3) | - | 5(6) | - | - | - | - |
| **Other** | 12 (8) | - | - | 5(6) | 2 (3) | 5 (8) | - | 5 (3) |
| **No response** | **94 (60)** | - | - | 8(9) | 15 (25) | 11 (16) | - | **74 (48)** |
| **Total** | 156 | 33 | 4 | 84 | 63 | 68 | 14 | 153 |

**9- Localizing the deficits in the reading aloud system.** For each of the individuals we attempted to identify the locus of the deficit in the reading aloud system based on the error type using the Dual-Route Model. Results in Table 21, in analysis 6a, showed that all subjects were unable to read non-words and this indicate impaired sub-lexical route with impaired orthography-phonology conversion mechanism. The results presented in Table 36 below show the localization of the deficit in the lexical route components.

Table 36 shows that one subject (1516) exhibit the characteristics of impaired visual orthographic analysis, five subjects (0116, 0716, 0916, 1116, 1416) exhibit the typical pattern associated with impairment affecting semantic/morphological lexicon, one subject (0516) exhibit the pattern of phonological output lexicon impairment, five subjects (0316-0616, 0816, 1216, 1316) exhibit undifferentiated deficits, and two subjects (0416, 1016) had no dyslexia.

Table 36

*Localizing the reading aloud deficits in the lexical route*

| **Visual orthographic analysis** | **Semantic lexicon** | **Phonological out-put lexicon** | **Phonological assembly** | **Un-differentiated** | **No Dyslexia** |
|---|---|---|---|---|---|
| 1516 | 0116 | 0516 | 0214 | 0316 | 0416 |
| | 0716 | | | 0616 | 1016 |
| | 0816 | | | 1216 | |
| | 0916 | | | | |
| | 1116 | | | | |
| | 1316 | | | | |
| | 1416 | | | | |

Note: All participants had problems in sub-lexical route with impaired reading-aloud of non-words

Analyzing the qualitative characteristics and types of the reading aloud errors also helped to identify the types of acquired dyslexia seen in Arabic individual with Aphasia who participated in this study. Table 37 provides the types of acquired dyslexia for each participant.  One subject (6%) had the characteristic of letter-by-letter reading where some or all of the letters of the word will be named (sometimes misnamed) before a response is produced. This is a consequence of impaired reading at the visual orthographic analysis level. Three subjects (20%) showed the characteristic of phonological dyslexia results from impaired sub-lexical reading route (orthographic-to-phonological conversion) relative to lexical reading. Characteristic features poor non-words reading and relatively better real words reading.

In addition, error types in reading aloud consist mainly of visual errors with the effect of imageability or word frequency. The data also revealed seven subjects (46%) with deep dyslexia. This is a result of reading via an impaired semantically lexicon level and impaired sub-lexical route. Error types consisted mainly of semantic and morphological errors. Two subjects (14%) showed mixed dyslexia (surface and phonological) where they had impaired sub-lexical route and poor performance on reading irregular words compared to regular words. Two subjects (14%) had no dyslexia.

Table 37

*Types of Dyslexia*

| Letter-by-Letter reading | Phonological Dyslexia | Deep Dyslexia | Mixed Dyslexia | Undifferentiated | No Dyslexia |
|---|---|---|---|---|---|
| 1516 | 0216 | 0116 | 0316 | - | 0416 |
| | 0616 | 0716 | 0516 | | 1016 |
| | 1216 | 0816 | | | |
| | | 0916 | | | |
| | | 1116 | | | |
| | | 1316 | | | |
| | | 1416 | | | |

**Summary of Findings.** Table 38 below summarizes the type of spelling and reading aloud impairment for each individual with their type of aphasia. It can be seen that all subjects had spelling and reading aloud impairment, except one subject (1016) who showed only acquired dysgraphia with intact reading aloud, and one subject (0416) with no acquired dysgraphia or dyslexia. Spelling impairment showed three main types of dysgraphia: phonological (n=3), mixed (n=4), and graphemic buffer (n=7). Reading aloud impairment showed four types of dyslexia: phonological (n=3), deep (n=5), mixed (n=4), and Letter-by-Letter (n=1).

Table 38

*Type of Aphasia, dysgraphia, and dyslexia for each participant*

| Case | Site of lesion | Type of Aphasia | Type of Dysgraphia | Type of Dyslexia |
|---|---|---|---|---|
| **0116** | Left MCA,subcortical (BG) | Subcortical (BG) | GB Dysgraphia | Deep Dyslexia |
| **0216** | Left peri-insular, frontal and superior temporal. | TCM | Mixed Dysgraphia | Phonological Dyslexia |
| **0316** | Left MCA | Broca's | Phonological Dysgraphia | Mixed Dyslexia |
| **0416** | Left MCA | Mild Anomia | No Dysgraphia | No Dyslexia |
| **0516** | Left posterior parietotemporal lobe | Anomia | GB Dysgraphia | Mixed Dyslexia |
| 0616 | Left temporal lobe & precentral gyrus | Jargon | Phonological Dysgraphia | Phonological Dyslexia |
| **0716** | Left MCA | Anomia | GB Dysgraphia | Deep Dyslexia |
| **0816** | Left MCA | Broca's | Mixed Dysgraphia | Deep Dyslexia |
| **0916** | Left MCA | Anomia | GB Dysgraphia | Deep Dyslexia |
| **1016** | Left frontal, insular, frontal opercular, subcortical parenchymal. | Anomia | Mixed Dysgraphia | No Dyslexia |
| **1116** | Left posterior frontal-parietal-temporal | Conduction | GB Dysgraphia | Deep Dyslexia |
| **1216** | Left temporal-parietal lobe, BG | Subcortical (BG) | Mixed Dysgraphia | Phonological Dyslexia |
| **1316** | Left MCA | Broca's | Phonological Dysgraphia | Deep Dyslexia |
| **1416** | Left parietal lobe, postcentral gyrus | Broca's | GB Dysgraphia | Deep Dyslexia |
| **1516** | Left anterior superior frontal lobe | TCM | GB Dysgraphia | Letter-by-Letter reading |

Basal Ganglia (BG), Transcortical Motor (TCM), Graphemic Buffer (GB).

**Section Four: Summary of the Results**

In this section, group results will be presented exploring the research questions posed in Chapter III.

**RQ1- Does lexical route processing influence spelling and reading aloud performance accuracy of Arabic individuals with aphasia (AIWA)?** Chi-square of difference in analysis 1a and 6a showed that all participants performed better with real words compared to non-words in spelling and reading aloud tasks (see Figure 8-9). This supports an impaired sub-lexical route in spelling and reading aloud.

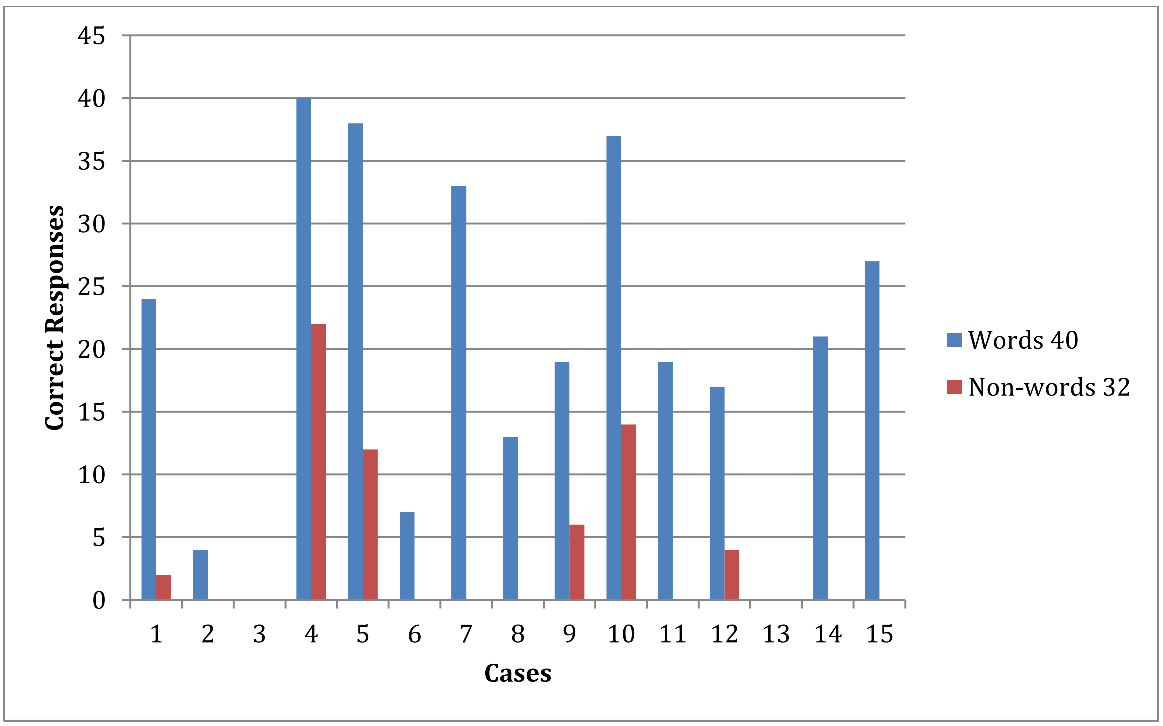


*Figure 8. .* Individual performance on spelling words and non-words.

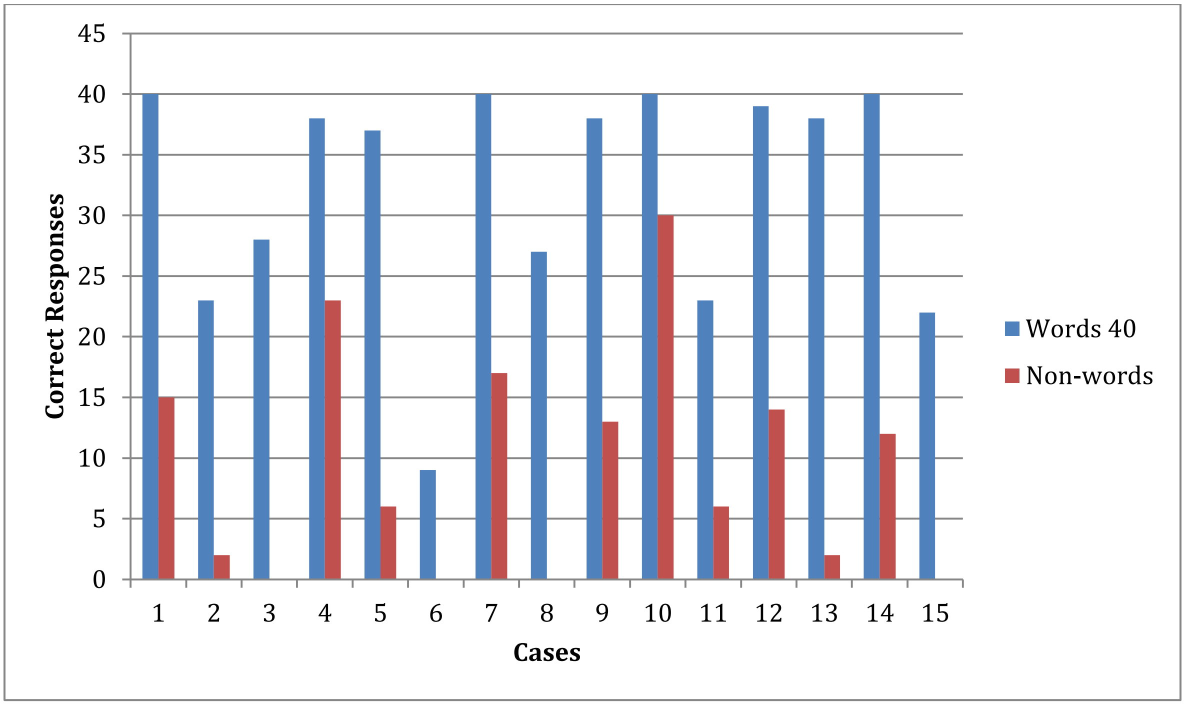


*Figure 9.* Individual performance on reading aloud words and non-words.

***H1a. Surface dysgraphia will occur more frequently than other types of dysgraphia in AIWA.*** By localizing the deficit in the spelling system, surface dysgraphia **was not** present in any participant. Thus not supporting the hypothesis that surface dysgraphia will occur more frequently, and H1a will be **rejected**. Analyzing the error types reveled that 46% (n=7) of the participants had a post-lexical deficit at the graphemic level, 20% (n=3) had phonological dysgraphia, and 27% (n=4) had mixed dysgraphia.

***H1b. Surface dyslexia will occur more frequently than other types of dyslexia in AIWA.*** Similar to $H1_a$, **none** of the participants **exhibit** the characteristics of surface dyslexia. Thus not supporting the hypothesis that surface dyslexia will occur more frequently, and H1b will be **rejected**. By localizing the deficit in the reading aloud system, as well as, analyzing the error types it was apparent that 33% (n=5) of the participants had deep dyslexia, 27% (n=4) had mixed dyslexia (i.e. characteristics of impairment to the lexical and sublexiacl route), 13% (n=2) exhibit phonological dyslexia, 7% (n=1) exhibit letter-by letter reading with a deficit at the visual orthographic analysis, and 7% (n=1) had undifferentiated reading aloud impairment.

***H1c. Spelling accuracy of regularity and lexicality word list will predict the occurrence of surface dysgraphia in AIWA.*** Surface dysgraphia **was not** present for any participant. But we are also interested to see if regularity and lexicality will predict spelling accuracy in general. Results, as seen in table 16, revealed that regularity and lexicality variables were not strong predictors for spelling accuracy and the hypothesis will be **rejected**. Binary logistic regression analysis 2a showed that lexicality has statistically significant predictive effect on spelling accuracy for only four subjects, and analysis 2c showed that regularity variable was statistically significant predictor ($p < .05$) in spelling accuracy for three subjects.

***H1d. Reading aloud accuracy of regularity and lexicality word list will predict the occurrence of surface dyslexia in AIWA.*** Pure surface dyslexia **was not apparent** in any participant. However, similar to $H1_c$ we are interested to see if regularity and lexicality will predict reading aloud accuracy in general. Results, seen in Table 33, revealed that lexicality variable was one of the strong predictors for reading aloud accuracy followed by regularity variable. Therefore, the hypothesis that "reading aloud accuracy of regularity and lexicality words will predict the occurrence of dyslexia in AIWA" will be **accepted.** Binary logistic regression analysis 7a showed that lexicality has statistically significant predictive effect on reading aloud accuracy for seven subjects, and analysis 7c showed that regularity variable was statistically significant predictor ($p < .05$) in reading aloud accuracy for five subjects.

**RQ2. Does Arabic morphology influence spelling and reading aloud performance accuracy of AIWA?** Arabic language has two main types of morphological systems; the derivational morphology (called lexical morphology) that is how words are formed, and inflectional morphology that is how words interact with syntax. In this study we analyzed these two types separately. Derivational morphology **was more predictive** compared to the inflectional morphology. In addition, derivational morphology **had more** number of participants with statistical significant results in predicting spelling accuracy compared to predicting reading aloud accuracy.

***H2a. Rates of morphological error types in writing to dictation will be higher than the other error types.*** In writing to dictation task, the rate of morphological error type was not dominant in comparison with other lexical and word errors such as omission of letters, and other errors. Therefore, the hypothesis will be **rejected**.

***H2b. Rates of morphological error types in reading-aloud will be higher than the other error types.*** Analyzing the error types in reading-aloud task revealed that morphological errors were more dominant than the other types of errors and the hypothesis will be **accepted**.

**RQ3. What are the indicators of orthographic working memory (OWM) impairment in acquired dysgraphia and dyslexia in Arabic?** Word length and error types are the main indicators for orthographic working memory (OWM) impairment in acquired dysgraphia and dyslexia.

Chi-square of difference analysis 1d showed that all subjects had statistically significant difference ($p < .05$) in spelling short words compared to long words (see figure 9). In addition, chi-square of difference analysis 6d showed that all subjects had statistically significant difference ($p < .05$) in reading-aloud short words compared to long words (see Figure 10).

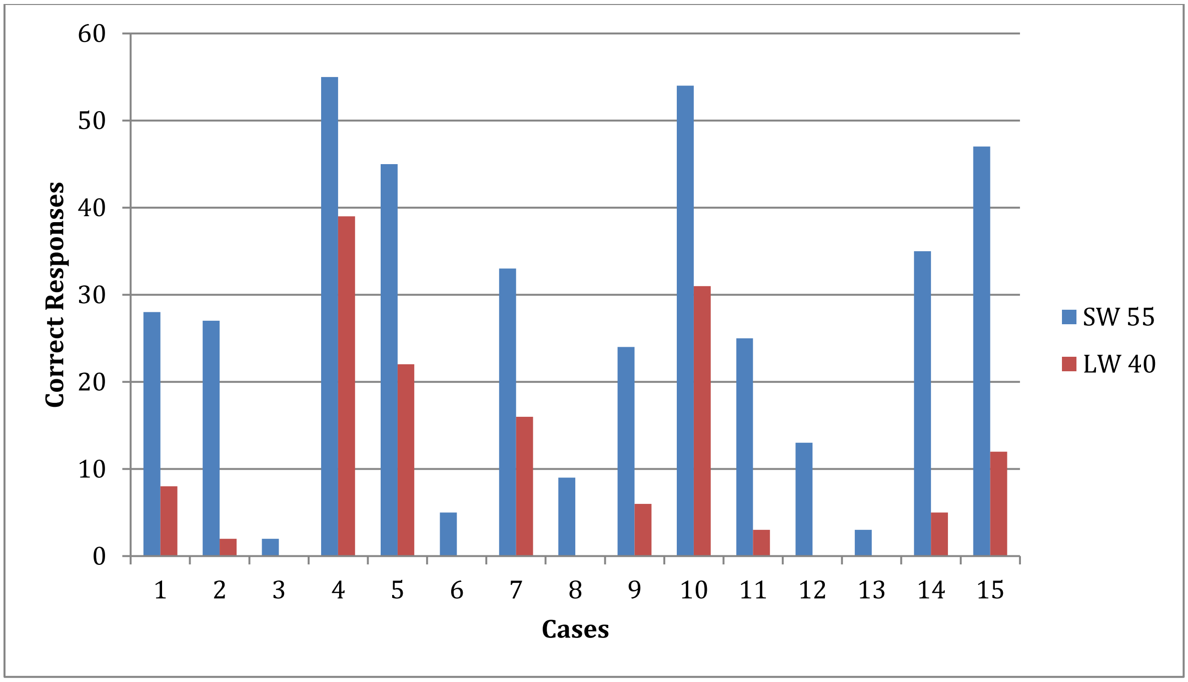


*Figure 10.* Individual performance on spelling short words (SW) and long words (LW).

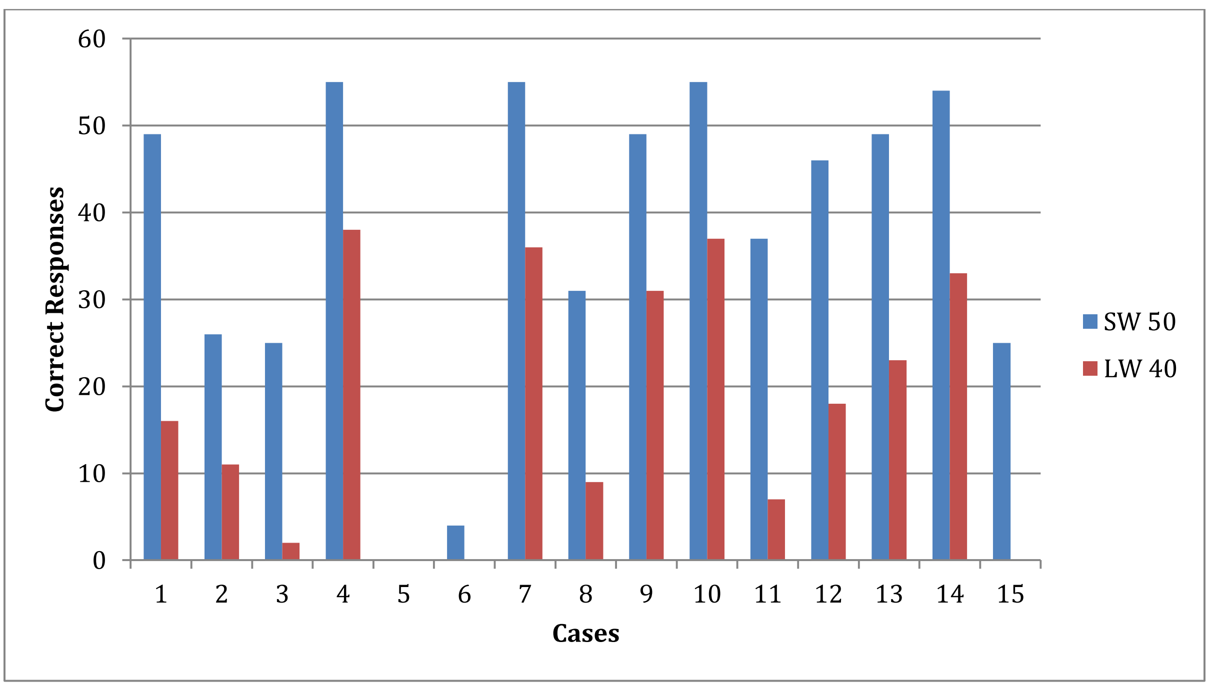


*Figure 11.* Individual performance on reading aloud short words (SW) and long words (LW).

***H3a. Word length errors will predict spelling accuracy.*** Word length was a strong predictor for spelling accuracy, thus the hypothesis will be **accepted**. Findings of the binary logistic regression analysis 2d showed that word length was statistically significant predictor ($p < .05$) in spelling accuracy. In addition, word length had the highest participants number (n=8), in terms of predicting spelling accuracy, compared to the other variables as seen in Table 16.

***H3b. Presence of a serial position effect in writing to dictation task.*** Serial position effects were computed for 7 subjects who showed the characteristics of graphemic buffer impairment. As seen in analysis 5, only one subject (1116) showed a clear bow-shaped pattern showing better performance at the beginning and end of words as seen above in Figure 7.

***H3c. Word length errors will predict reading aloud accuracy.*** Similar to H3a, word length was a strong predictor for reading-aloud accuracy, thus the hypothesis will be **accepted**. Binary logistic regression analysis 7d shows that word length was statistically significant predictor for reading aloud accuracy ($p < .05$) in seven subjects. In addition, as seen in Table 33, word length is the most variables that have significant prediction on reading aloud accuracy (n=7).

***H3d. Presence of serial position effect in reading aloud task.*** Serial position effect in reading aloud task was unable to be computed as no subjects showed characteristics of orthographic working memory impairment in reading aloud task. Therefore, the hypothesis was rejected.

**RQ4. Does morphological complexity influence orthographic working memory?** Word length in Arabic ranges from 3-9 letters and it increases in relation with increased morphological complexity (i.e. roots are short words with 3-letters, and derivatives are longer words with more than 4-letters). As seen in RQ3, word length is a main indicator for orthographic working memory (OWM) impairment in acquired dysgraphia and dyslexia.

In the morphological list, findings of the Chi-square of difference analysis 1e showed that all subjects had statistically significant difference ($p < .05$) in spelling simple-short words compared to complex-long words (see Figure 12). In addition, chi-square of difference analysis 6e showed that all subjects had statistically significant difference ($p < .05$) in reading-aloud simple-short words compared to complex-long words (see Figure 13).

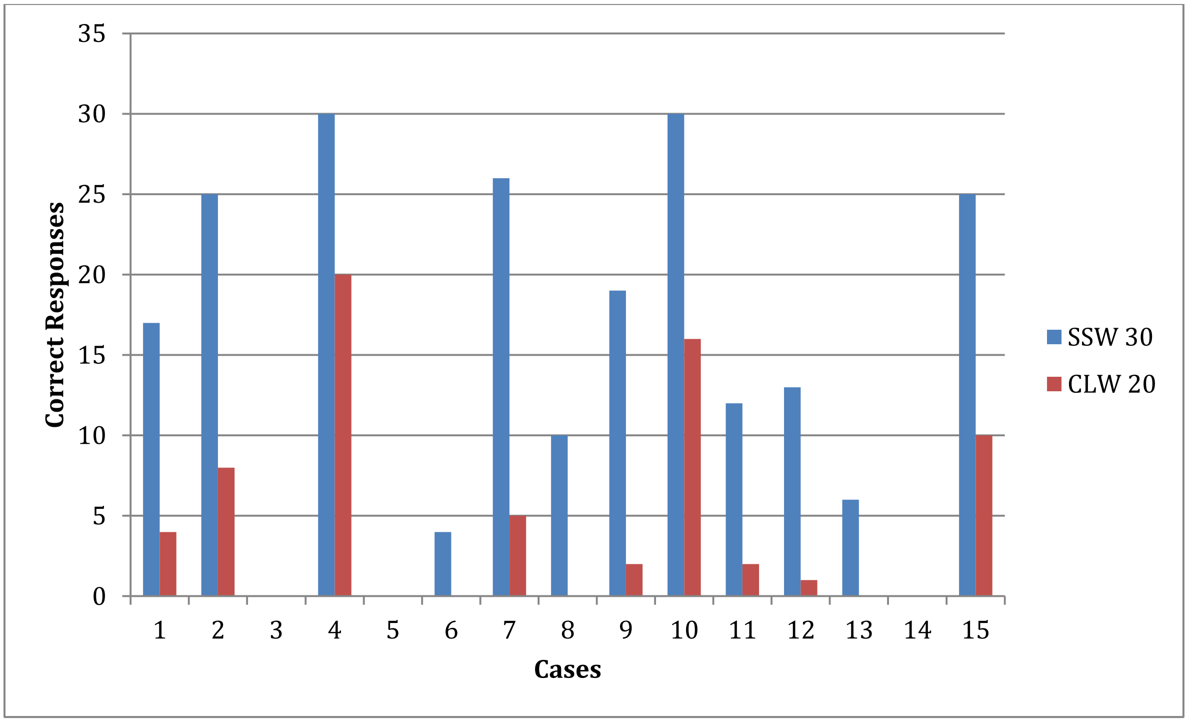


*Figure 12. Individual performance on spelling simple-short words (SSW) and complex-long words (CLW).*

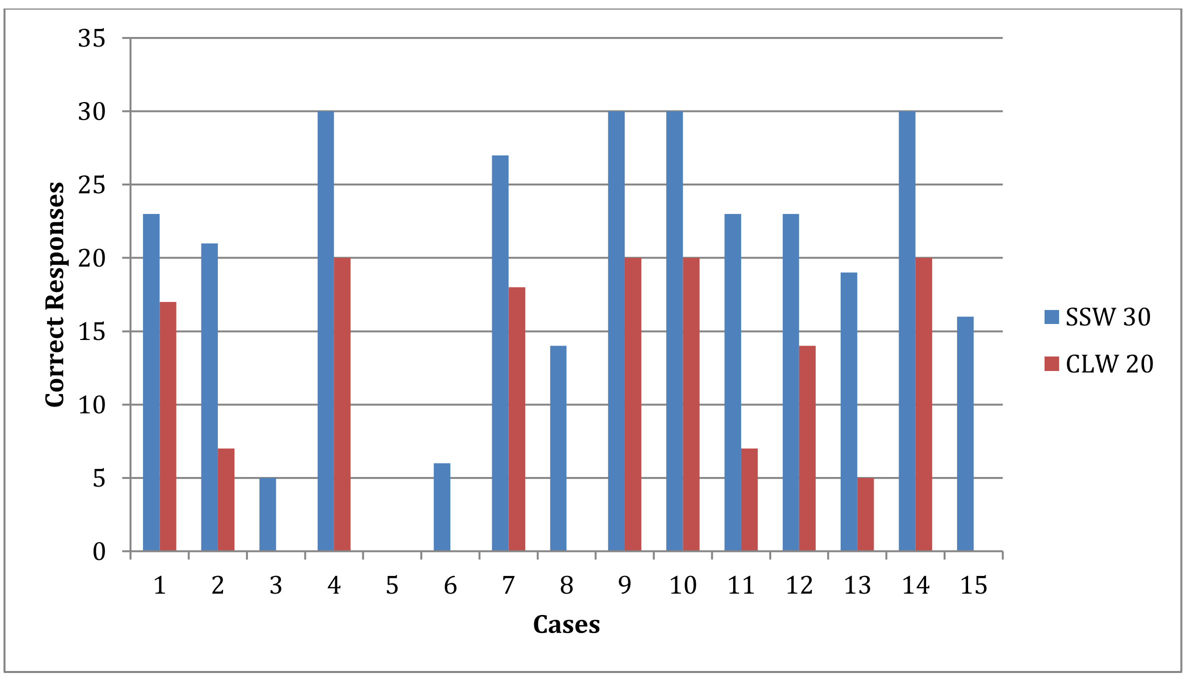


*Figure 13.* Individual performance on reading aloud simple-short words (SSW) and complex-long words (CLW).

***H4a. Complex morphological words will predict spelling accuracy.*** Binary logistic regression analysis 2f shows statistically significant results of complex morphological words on spelling accuracy. Thus the hypothesis will be **accepted**.

***H4b.Complex morphological words will predict reading aloud accuracy.*** Derivational morphology was not a strong predictor in reading-aloud accuracy. Thus the hypothesis will be **rejected**.

# DISCUSSION

The aim of this study was to assess the universality assumption of the dual route model (DRM) for spelling and reading aloud in Arabic individuals with aphasia (AIWA). The study focused on three predictions: performance pattern for spelling and reading aloud via impaired lexical route, performance pattern for spelling and reading aloud via impaired morphological/semantic system, and performance pattern for spelling and reading aloud via impaired orthographic working memory.

The study results were secured by using case series method analysis of each individual participant's performance specific to the dependent variables spelling and reading-aloud accuracy. The descriptive and demographic results showed that participants were heterogonous with huge variability and the option to use the case series method enabled preservation and analysis of each individual's performance. In addition, the usefulness of using such a method was appreciated by its ability to give an in-depth understanding of the problems encountered by each individual. The Case series method offered the ability to look into each individual's symptoms and error types and also to take into account individual variances.

Participants in this study were not grouped for statistical testing, however, they were assigned to different categories based on their symptoms. It was important to examine patterns across patients, not just within individuals, to know if there are any themes emerging with any particular aphasia syndrome. We agree with Schwartz and Dell (2010) that though case series studies are less concerned with means and more concerned with trends, trends themselves can be heterogeneous and the lack of homogeneity of the groups can limit our conclusions. However, using this method offers the potential to understand this heterogeneity and provide foundational work for advancing theory. Finally, in case series analysis, it is applicable to see if each participant's measurement can be characterized as consistent with the model or not using logistic regression, and to explain the deviating cases by using single-subject style assessment (Schwartz & Dell, 2010). Thus, this approach to reviewing the data was utilized.

The patients discussed in this study demonstrated different range of impairments in spelling and reading aloud tasks. They showed marked problems with the performance in both tasks that are designed to test the integrity of the components or modules and processes that are hypothesized by the DRM model. The DRM model assumes the presence of two routes, lexical and sub-lexical, in spelling and reading aloud tasks. In this framework, the lexical route is the only pathway when spelling or reading aloud irregular-words, and the sub-lexical route is the only option when spelling or reading aloud non-words. The relative involvement of the lexical and the sub-lexical routes in spelling and reading aloud depends on the degree of regularity or transparency of the language. Given that, Arabic language is considered as having a deep orthography system for skilled readers (Abu-Rabia & Taha, 2004), we predicted that the reliance on the lexical route would be more frequent and this will subsequently result in more surface dysgraphia and dyslexia. However, this prediction was not supported by our findings.

The study results show that all subjects who participated in the study had impaired sub-lexical route in spelling and reading aloud tasks, which was evident in their failure to spell or read aloud non-words compared to their performance on real words, with variable individual ability. In addition, some participants showed impaired components of the lexical route as well. The results yield different types of dysgraphia and dyslexia but no evidence of surface dysgraphia or surface dyslexia. This finding is more consistent with languages that have transparent or shallow orthography system such as Italian, Spanish, Slovak and Turkish. However, single case studies of surface dysgraphia and surface dyslexia were reported in the literature in language with shallow orthography (Luzzatti, et al., 1998; Luzzati, et al.,, 2006; Miceli, & Caramazza, 1993; Cuetos, 1993; Iribarren, et al., 2001; Toraldo, et al., 2006; Raman, & Weekes, 2005), yet, the percentages of this type might be considered low compared to languages with deep orthography such as English and French. The results of the current study are similar to Hircova and Weekes (2012) who analyzed acquired reading disorders in Slovak language that has transparent or shallow orthography and found no evidence of surface dyslexia in their sample of 30 participants. Though similarity between findings, we should not eliminate the differences between Arabic and Slovak orthography systems.

The findings of the present study also showed similar results in relation with data reported in studies of English orthography for English-speaking aphasia individuals. The spelling impairments of the 15 Arabic individuals with aphasia who participated in the present study covered the range of three main spelling impairment types, with majority having the characteristics of graphemic buffer dysgraphia (46%), followed by mixed dysgraphia (27%) and lastly phonological dysgraphia (20%). Reading aloud impairment, on the other hand, showed a wider range of impairment with four types of dyslexia, the majority was deep dyslexia (46%), followed by phonological dyslexia (20%), mixed dyslexia (14%), and a much lower incidence of letter-by-letter dyslexia (6%). The rates of dysgraphia and dyslexia subtypes reported in the literature have not been systematically described in terms of proportion in deep-orthography compared to shallow-orthography languages, to the best of our knowledge, and therefore direct comparison in our study is not possible. However, three interesting points of the present study are revealing: (i) the distribution of dysgraphia and dyslexia types are more in line with shallow orthographies, (ii) predominance of deep dyslexia in reading aloud, and (iii) mixed pattern of impairment in spelling and reading aloud.

The predominance of specific type of dysgraphia and dyslexia in certain orthographies and the comparative proportion differences suggest that the two routes have a different relevance in different languages (Luzzatti, 2008). Although, the study results did not show the expected dissociation patters of both lexical and sub-lexical route, we shall put in mind that the possibility of acquired surface dysgraphia and dyslexia in Arabic orthography should not be ruled out. Learning to read or write in

Arabic starts with instruction given in shallow vowelized orthography instead of the deep un-vowelized orthography, and a transition form shallow to deep starts around the 4th grade. So it is possible that Arabic orthography in skilled readers might favor one route over the other.  This view can be explained by the orthography depth hypothesis (ODH) proposed by Katz and Frost (1992), which state that each orthography, shallow or deep, defines its own pattern of contingencies.

ODH states that shallow orthographies have consistent letter-to-phoneme correspondence that support a simple and easy word recognition process through phonological mediation (i.e., sub-lexical route), whereas deep orthographies depend on context and encourage a reader to access the morphology of the word through its visual structure (i.e., lexical route). Arabic orthography, similar to Hebrew, lacks most of the vowels and has many ambiguous consonants, and it is incapable of providing enough assembled phonology that will consistently identify a unique word in the phonological lexicon; therefore, there are fewer benefits in generating phonological information by assembling it from grapheme-phoneme correspondences (Katz & Frost, 1992).

The findings presented here support that one orthography can favor one route or the other. In the case of Arabic language, there is a reason for a skilled reader not to use a sub-lexical strategy and prefer the lexical mechanism to access word. We believe that there is nothing in the Arabic orthography that would prevent a reader from processing non-words and thus this issue needs to be further explored. The possibility of the presence of the two separate routes and the universality assumption of the dual-route model and their breakdown patterns in Arabic orthography may still offer insight and thus is still and area to investigate. We suggest, the findings from the current study support the assumption that to generalize the same dual-route model of single word processing to all languages, irrespective of their orthography and irrespective of the procedures used to teach reading skills during the early phases of literacy acquisition, is still an area of debate.

The study results showed a different pattern of reading aloud impairment with respect to spelling impairment. It seems that in Arabic language, reading and writing undergo a different breakdown pattern, which was similarly reported in other studies (Hricova & Weekes, 2012; Toraldo et al., 2006). The relationship between reading and spelling processes is one of the most debated questions in written language research. One view is explained by the independent lexicon theory (ILT) which claims that reading (input orthography) and spelling (output orthography) relay on separate processing components (Rapp, Benzing, & Crammazza, 1997), while an alternative view explained by the common lexicon theory (CLT) suggests that reading and spelling share same components or one single lexicon (Behrmann & Bub, 1992; Tainturier & Rapp, 2001; Balasubramanian & Costello, 2011).

In addition, the current study findings did not support the existence of a trend in the data specific to the relationship between aphasia and dysgraphia and dyslexia classifications. The classification of patients according to aphasic syndromes does not imply that there is an identical spelling and reading aloud impairments in subjects sharing the same aphasia characteristics (i.e. Broca's, Wernicke's and so on) confirming previous research (Balasubramanian, 2005; Luzzatti, et al., 1998). In Italian multiple case study by Luzzatti, et al., (1998) results reported no relationship found between type of aphasia and type of dysgraphia, but trend was found in reading impairment in a study by Toraldo et al., (2006), where the majority of Broca's aphasic patients suffered from phonological dyslexia and fluent aphasic were distributed more evenly across dyslexia types.

Emerging from the present study is an interesting issue, the mixed pattern of spelling and reading aloud impairments. This mixed pattern characterized by damage to the sub-lexical route in addition to damage to at least one component of the lexical route was also reported in Italian orthography in spelling impairments (Luzzatti et al., 1998). As we seek to understand this observation, one may explain the mixed pattern of impairment via the summation hypothesis proposed by Hillis and Caramaza (1991), which, suggests an interaction between the two routes. Such an interaction is hypothesized to take place in oral reading and in writing to dictation. Thus, the role of the interaction between lexical and sub-lexical processing mechanisms in Arabic orthography could be an interpretation of the observed pattern.

A further observation in the present study concerns error types. The error patterns observed in the spelling task showed three main types: omission of letters, orthographically similar words (words or non-words), and regularization. The first two types were more prominent and only one subject had regularization error. The error patterns observed in the reading-aloud task were very different to the one observed in spelling. The evidence lies in the profile of errors in reading-aloud showed predominance morphological errors and visual errors followed by phonological errors.

Similarly, a study by Abu-Rabia and Taha (2004) on dyslexic and normal children showed that the most prominent reading errors were morphological across all groups.

The higher number of morphological errors observed in this study could be because Arabic language is rich with morphological structures, and because the similarity of words, visually and phonologically, that usually relate to the same root (Beland & Mimouni, 2001). This finding indicates that the reader of Arabic relies on word recognition strategies that involve phonological decoding skills, visual–orthographic recognition, and high morphological mapping as explained by ODH. As a consequence of theses morphological errors, more deep dyslexia was observed.

Another interesting and important point to discuss is the orthographic working memory (OWM), or graphemic buffer (BG), impairment in spelling. The participants with impairment to OWM in this investigation showed the effects of word length, in addition, they had error types that consisted mainly of letter omissions, and spelling accuracy was not affected by lexical factors such as word frequency or imageability. These findings are consistent with graphemic buffer dysgraphia cases reported in literature (Caramazza, Capasso, & Miceli, 1996, Tainturier & Rapp, 2003). Another feature of the OWM is the serial position accuracy function. In this study, participants with OWM impairment did not exhibit the bow-shaped effect, except of one subject (Balasubramanian, Aldera, & Costello-Yacano, 2015; Miceli et al., 2004; Schiller et al., 2001; Ward & Romani, 1998). However, more errors in the middle letters of the word were noted compared to the initial and final letters. We agree with Rapp and Kong (2002); and Sage and Ellis (2004) that the difference between the individuals reported in this study and those discussed in the literature, in terms of the serial effect or bow-shaped curve, are likely to be the result of disruption to different components or sub-components of the orthographic working memory, whose structure is yet to be fully understood.

The length of the stimuli also showed a significant effect on the reading aloud performance. However, no evidence was found in this study on the possible shared graphemic buffer component between spelling and reading aloud. Participants in this study, who had graphemic buffer impairment, had different error types when reading aloud either words or non-words. Some studies in the literature (Caramazza et al., 1996; Tainturier & Rapp, 2003) proposed that graphemic buffer might be also involved in maintaining the level of activation of input representations of a letter string for reading. The main empirical motivation to this hypothesis was from observations of non-word reading disorders in patients with GB impairment. Caramazza et al., (1996); and Tainturier and Rapp (2003) reported single subjects who had spelling performance suggested a deficit in GB level, and quantitatively and qualitatively similar reading performance of non-words. Debate is still open regarding the role of GB in reading. Most studies were not conclusive, and the limited number of subjects used in these studies might have an effect on the outcome.

# Chapter V

# SUMMARY & CONCLUSIONS

This chapter highlights the results of the current study and the conclusion drawn for the universality principle of the DRM. Moreover, the limitations of the study are explicitly stated and the need for future research is outlined.

## Conclusion

The current study demonstrated that cognitive neuropsychological research allows for testing models of cognitive processing. However, our predictions based on the universality assumption of the dual-route model (DRM) and the nature of Arabic orthography regarding the aphasic clients' reading and spelling performance have not yielded anticipated results.  All of the components hypothesized by dual-route model were impaired to some degree in each participant. In our view, these components are cognitive functions that, in Arabic skilled reader, comprise a highly practiced mechanism specialized for spelling and reading aloud. Elements of these components, such as the sub-lexical route may be involved differently and that the relative impact of both routes varies substantially from one script to the other.

The degree of the orthographic regularity and transparency usually determine the relative involvement of the lexical and the sub-lexical routes in spelling and reading aloud processing. Since, Arabic language has a deep orthography system for skilled readers, we predicted that the reliance on the lexical route would be more frequent and will subsequently result in more surface dysgraphia and dyslexia. However, contrary to the prediction, the contribution of the sub-lexical route in spelling and reading-aloud was not seen and there was no evidence of surface dysgraphia or dyslexia. Despite the absence of surface type, the present study showed that Arabic individuals with aphasia (AIWA), who participated in the study, had patterns of acquired dysgraphia and dyslexia that are similar to the ones reported in languages with deep orthography such as English and French, as well as languages with shallow orthography such as Italian and Slovak.

The types of dysgraphia and dyslexia that were predicted by the DRM of spelling and reading-aloud, suggest that qualitatively similar cognitive architectures for spelling and reading-aloud can also develop in Arabic orthography. Although, the study results did not show the expected dissociation patters of both lexical and sub-lexical route, the possibility of occurrence of acquired surface dysgraphia and dyslexia in Arabic orthography should not be ruled out. It is still an open question whether there are two distinct routes in Arabic orthography and how much each route is engaged in processing spelling and reading-aloud under the umbrella of the DRM model.

The results also showed that error types analysis have its unique role in determining the location of deficit within the impairment-based approach and can be discreetly applied to identify types of dysgraphia and dyslexia. The error patterns observed in the spelling task were predominantly omission of letters yielding more proportion of graphemic buffer dysgraphia. On the other hand, the error patterns observed in the reading-aloud task were predominant morphological and visual yielding more deep dyslexia. The nature of Arabic orthography in reading-aloud task contributed to deliver a specific profile of errors such as morphological errors. These error types enabled us to understand the profile of reading-aloud in AIWA and contributed to understand the cognitive neuropsychology profile for each participant.

In conclusion, we hope that results such as those of the present study help advance knowledge on spelling and reading-aloud impairment in AIWA. We also hope that the results will serve as a basis for cognitive neuropsychological evaluation and interventions of acquired writing and reading aloud impairment given the unique characteristics of the Arabic orthography.

**Limitations**

Although the present study has yielded some preliminary findings, there were some important limitations. These limitations were in the three phases of development of this dissertation: the preparation stage, the implementation stage, and the statistical analysis stage.

In the preparation stage, developing the testing stimuli was subject to large amount of variations as the testing material attempted to evaluate complex and large sets of words at different levels. In addition, the testing material lacks the test on normal population.

During the implementation stage, there were some difficulties in recruiting participants due to holiday period and due to the control of the speech-language pathologists (SLPs) to invite the potential participant. Moreover, the aphasia classification was reported by the SLPs who are in charge of the participants, and some medical information such as MRI or CT scan was not available for some participants. In addition, the attempt to test words at various levels of complexity led to some administration difficulties. Some participants occasionally reported difficulties and refused to perform the task, such as spelling of non-words. Further more, participants consented to a minimum of four sessions and were happy to continue if needed, but most conceded at the end that they were glad that it was finished because it was long and tiring. Therefore, to avoid fatigue it will be better to have a limit on the number of assessments conducted per session.

Finally, in the Analysis stage there is a limitation to generalize results due to sample size and the convenience of the sample. Furthermore, the findings of the current study cannot be generalized across a wider population of individuals with aphasia due to the use of case series design. Aphasia is an extremely heterogeneous condition, with each individual presenting with different symptoms and levels of severity of impairment in expressive and receptive language. A further disadvantage of the small sample size was that it was not possible to use statistical methods, e.g. multiple regression analyses, to examine the relationships or correlation between different variables. However, there is scope for these data to be analyzed further in future studies to explore the differences across genres.

## Implications

This study is a novel contribution to the literature on acquired dysgraphia and dyslexia in Arabic individuals with aphasia. Results such as those of the present study will hopefully advance knowledge on written word processing in Arabic language, and serve as a basis for cognitive neuropsychological assessment which focus specifically on the different patterns of impairment observed in each type of dysgraphia and dyslexia. This study also showed the usefulness of using case series method to investigate individuals with aphasia.

The study also showed a valuable clinical implication of using the dual-route model in providing a theoretical framework in which the abilities of Arabic individuals with aphasia could be investigated, and thus enables SLPs to formulate hypotheses about which processing mechanisms are impaired. These in turn help the SLPs to determine and deliver adequate patient centered treatment design.

**Future Recommendations**

We hope that this study will encourage further research in the field of Aphasia in Arabic language, with the aim to develop further understanding of the relations between individuals with aphasia and different type of impairment in language modalities, under the umbrella of cognitive neuropsychology approach, so that appropriate and accurate assessment can be offered whenever possible.

A clear foundation must be set that can latter support inferences of causality as well as conclusions that can be generalized to the larger population being sampled. Direction for future research in acquired reading and writing disorders are needed in the area of clinical assessment, treatment, and research. Furthermore, it is an important benefit to standardize the assessment tool that will aid in carrying out adequate assessment of reading and writing in Arabic orthography.

Finally, research combining functional and structural neuroimaging with behavioral performance is needed to determine the precise mechanism and nature that account for acquired dysgraphia and dyslexia.

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## Appendix 1

## Sample of The Testing Material

### Test Stimuli

**1. Grammatical Word Class**

List composition: 105 words (40 Nouns, 30 Verbs, 20 Adjectives, 15 Functors).

| No. | Target Arabic | Class | IPA | English Translate | No. | Target Arabic | Class | IPA | English Translate |
|---|---|---|---|---|---|---|---|---|---|
| 1 | طريق | N- HF | *arig* | Road | 1 | قميص | N-LF | *Qmi:* | Shirt |
| 2 | باب | N- HF | *ɓa:ɓ* | Door | 2 | رقبة | N-LF | *raqabħ* | Neck |
| 3 | محطة | N- HF | *ma a a* | Station | 3 | ليمون | N-LF | *Lai:mon* | Lemon |
| 4 | صندوق | N- HF | *nduq* | Box | 4 | باخرة | N-LF | *ɓa irah* | Steamship |
| 5 | مسجد | N- HF | *ms d* | Mosque | 5 | خشب | N-LF | *a aɓ* | Wood |
| 6 | عين | N- HF | *ai:n* | Eye | 6 | فيل | N-LF | *fi:ʆ* | Elephant |
| 7 | مويه | N- HF | *mu:i:ah* | Water | 7 | حاسوب | N-LF | *asuɓ* | Computer |
| 8 | ورقة | N- HF | *waraqah* | Paper | 8 | بطاطس | N-LF | *ɓa a is* | Potato |
| 9 | دولة | N- HF | *daulah* | Country | 9 | مصحف | N-LF | *mus af* | Quran |
| 10 | ولد | N- HF | *walad* | Boy | 10 | حبل | N-LF | *aɓʆ* | Rope |

**2. Non-words**

List composition: 32 non-words

| No. | Target Arabic | Class | IPA | No. | Target Arabic | Class | IPA |
|---|---|---|---|---|---|---|---|
| 1 | بطرم | 4-letters | *ɓa ram* | 1 | زوندقي | 6-letters | *zundaqi:* |
| 2 | فيون | 4-letters □ | *fi:un* | 2 | درازوم | 6-letters□ | *dara:zu:m* |
| 3 | قبيش | 4-letters □ | *qabi:* | 3 | قرنقوط | 6-letters□ | *Qarnqu:* |
| 4 | سافي | 4-letters □ | *safi:* | 4 | مساليل | 6-letters□ | *masali:ʆ* |
| 5 | رابك | 4-letters □ | *rabik* | 5 | كاديرا | 6-letters□ | *kadi:ra* |
| 6 | سبرة | 4-letters □ | *sabrah* | 6 | عركبوت | 6-letters□ | *rkabu:t* |
| 7 | خفرة | 4-letters □ | *afrah* | 7 | فشاريد | 6-letters□ | *f ari:d* |
| 8 | مهيد | 4-letters □ | *mahi:d* | 8 | مزكروج | 6-letters□ | *mazkaru:* |

**5. Regularity Spelling**
List composition: 60 Words (30 Vowelized, 30 Un-vowelized)

| No. | Target Arabic | Class | IPA | English Translate | No. | Target Arabic | Class | IPA | English Translate |
|---|---|---|---|---|---|---|---|---|---|
| 1 | إمام | V | *i:mam* | Leader | 1 | سمك | UV | *samak* | Fish |
| 2 | كُرسي | V | *kursi:* | Chair | 2 | ميزان | UV | *mi:zan* | Scale |
| 3 | لاءَم | V | *la-ma* | Suit | 3 | تاج | UV | *ta:* | Crown |
| 4 | الليل | V | *alai:l* | Night | 4 | حريق | UV | *ari:q* | Fire |
| 5 | مُسجل | V | *musa l* | Recorder | 5 | وهب | UV | *u:haba* | Offer |
| 6 | طاووس | V | *au:s* | Peacock | 6 | قلعة | UV | *ql ah* | Castle |
| 7 | مُكيف | V | *mukai:f* | Air-condition | 7 | شبكة | UV | *abaka* | Net |
| 8 | صباحًا | V | *aba n* | Morning | 8 | نسيم | UV | *nasi:m* | Breeze |
| 9 | تغيير | V | *ta i:r* | Change | 9 | دقيقة | UV | *daqi:qah* | Minute |
| 10 | نقاهه | V | *naqaha* | Recovery | 10 | حيوان | UV | *i:au:an* | Animal |

**7. Morphology**
**7.a. Derivative morphology:** List composition: 15 sets (each set consist of 5 derivative morphological structures, ranging from 3-letter words (root) to 7-letter words).
(فَعَل فاعِل تَفاعُل مُفاعلة إستفعال)

| No. | Target Arabic | Class | IPA | English Translate | No. | Target Arabic | Class | IPA | English Translate |
|---|---|---|---|---|---|---|---|---|---|
| 1 | كَتَبَ | Root | *kataba* | Write | 11 | رَفَعَ | Root | *rafa a* | Raise |
| | كاتِب | 4-L | *ka:tib* | | | رافِع | 4-L | *rafi* | |
| | تكاتُب | 5-L | *taka:tub* | | | ترافُع | 5-L | *tarafu* | |
| | مُكاتبة | 6-L | *mukataba* | | | مُرافعة | 6-L | *murafa a* | |
| | إستكتاب | 7-L | *istiktab* | | | إسترفاع | 7-L | *istirfa:* | |

## Appendix 2

## Interclass-correlation coefficient (ICC)

### Intraclass Correlation Coefficient for Familiarity

| | Intraclass Correlation[b] | 95% Confidence Interval Lower Bound | Upper Bound | F Test with True Value 0 Value | df1 | df2 | Sig |
|---|---|---|---|---|---|---|---|
| Single Measures | .500[a] | .077 | .865 | 5.500 | 6 | 12 | .006 |
| Average Measures | **.750** | .200 | .951 | 5.500 | 6 | 12 | **.006** |

Two-way random effects model where both people effects and measures effects are random.
a. The estimator is the same, whether the interaction effect is present or not.
b. Type A intraclass correlation coefficients using an absolute agreement definition.

The average measure ICC was .75 with a 95% confidence interval from .20 to .95 ($F(6,12)= 5.5$, $p <.001$).

### Intraclass Correlation Coefficient for Readability

| | Intraclass Correlation[b] | 95% Confidence Interval Lower Bound | Upper Bound | F Test with True Value 0 Value | df1 | df2 | Sig |
|---|---|---|---|---|---|---|---|
| Single Measures | .625[a] | .161 | .913 | 5.500 | 6 | 12 | .006 |
| Average Measures | **.833** | .366 | .969 | 5.500 | 6 | 12 | **.006** |

Two-way random effects model where both people effects and measures effects are random.
a. The estimator is the same, whether the interaction effect is present or not.
b. Type A intraclass correlation coefficients using an absolute agreement definition.

The average measure ICC was .83 with a 95% confidence interval from .37 to .97 ($F(6,12)= 5.55$, $p<.001$).

**Intraclass Correlation Coefficient for Clarity**

| | Intraclass Correlation[b] | 95% Confidence Interval | | F Test with True Value 0 | | | |
|---|---|---|---|---|---|---|---|
| | | Lower Bound | Upper Bound | Value | df1 | df2 | Sig |
| Single Measures | .803[a] | .470 | .959 | 12.308 | 6 | 12 | .000 |
| Average Measures | **.925** | .726 | .986 | 12.308 | 6 | 12 | .**000** |

Two-way random effects model where both people effects and measures effects are random.
a. The estimator is the same, whether the interaction effect is present or not.
b. Type A intraclass correlation coefficients using an absolute agreement definition.

The average measure ICC was .93 with a 95% confidence interval from .73 to .98 ($F(6,12)= 12.31$, $p<.001$).

**Intraclass Correlation Coefficient of Comprehension**

| | Intraclass Correlation[b] | 95% Confidence Interval | | F Test with True Value 0 | | | |
|---|---|---|---|---|---|---|---|
| | | Lower Bound | Upper Bound | Value | df1 | df2 | Sig |
| Single Measures | .674[a] | .220 | .939 | 7.200 | 5 | 10 | .004 |
| Average Measures | .**861** | .459 | .979 | 7.200 | 5 | 10 | .**004** |

Two-way random effects model where both people effects and measures effects are random.
a. The estimator is the same, whether the interaction effect is present or not.
b. Type A intraclass correlation coefficients using an absolute agreement definition.

The average measure ICC was .86 with a 95% confidence interval from .46 to .98 ($F(6,12)= 7.20$, $p<.001$).

## Appendix 3

## IRB Letters of Approval

Kingdom of Saudi Arabia
Ministry of Health
King Fahad Medical City
(162)

مدينة الملك فهد الطبية
King Fahad Medical City

المملكة العربية السعودية
وزارة الصحة
مدينة الملك فهد الطبية
(١٦٢)

IRB Registration Number with KACST, KSA: H-01-R-012
IRB Registration Number with OHRP/NIH, USA: IRB00008644
Approval Number Federal Wide Assurance NIH, USA: FWA00018774

December 13, 2015
**IRB Log Number: 15-435E**
Department: External
Category of Approval: EXEMPT

Dear Maha Aldera,

I am pleased to inform you that your submission dated December 12, 2015 for the study titled '**Application of the Dual-Route Model in Exploring Dyslexias and Dysgraphias in Arabic Speaking Adults with Aphasia: Clinical and Theoretical Implications**' was reviewed and was approved. Please note that this approval is from the research ethics perspective only. You will still need to get permission from the head of department or unit in KFMC or an external institution to commence data collection.

We wish you well as you proceed with the study and request you to keep the IRB informed of the progress on a regular basis, using the IRB log number shown above.

Please be advised that regulations require that you submit a progress report on your research every 6 months. You are also required to submit any manuscript resulting from this research for approval by IRB before submission to journals for publication.

If you have any further questions feel free to contact me.

Sincerely yours,

***Prof. Omar H. Kasule***
Chairman Institutional Review Board--IRB.
King Fahad Medical City, Riyadh, KSA.
Tel: + 966 1 288 9999 Ext. 26913
E-mail: okasule@kfmc.med.sa

13 DEC 2015

مدينة سلطان بن عبد العزيز للخدمات الإنسانية
SULTAN BIN ABDULAZIZ HUMANITARIAN CITY

**RESEARCH & ETHICS COMMITTEE**

*31st January 2016*

**MS. MAHA ALDERA**
***Principal Investigator***
**SLP Doctoral Student**
**Seton Hall University**
**South Orange, New Jersey, U.S.A.**

**Subject :** **"Application of the Dual-Route Model in Exploring Dyslexias and Dysgraphias in Arabic Speaking Adults with Aphasia: Clinical and Theoretical Implications"**

***Dear Ms. Maha:***

Thank you for submitting your research proposal.

The above mentioned proposal has been reviewed by the assigned members of the Research and Ethics Committee of the Sultan bin Abdulaziz Humanitarian City, Riyadh. I am pleased to inform you that this project has been approved by Research and Ethics Committee (Chairman Action).

Your research protocol has now been documented under:

| | | |
|---|---|---|
| **Project Number** | : | **001/2016/28th January 2016** |
| **Series of** | : | **2016 January** |

Kindly quote the project number indicated herein in all transactions and communications. You are advised to submit a progress report, this time after three (3) months from approval of your research proposal, in relation to this research schemed we need you also to send us a Final report after your research will be completed in relation to this research schemed to update the committee of its results.

I trust your research scheme proves fruitful and beneficial to you, the patients and this institution.

Thank you.

*Best regards,*

**Dr. Sadi Al Zahrani, SLP Cons.**
***Chairman of Research & Ethics Committee***
**Sultan Bin Abdulaziz Humanitarian City**
P.O. Box 64399, Riyadh 11536
Kingdom of Saudi Arabia

مستشفى الملك فيصل التخصصي ومركز الأبحاث
King Faisal Specialist Hospital & Research Centre
Gen. Org. مؤسسة عامة

**Office of Research Affairs**
**☎32907 🖷 27894 ✉MBC 03**
**INTERNAL MEMORANDUM**

| | | | |
|---|---|---|---|
| **TO:** | **Maha Abdulatif Alderea, MSc, SLP**<br>Speech Language Pathologist<br>Otolaryngology/Head & Neck Surgery/Communication Sciences Department | **DATE:** | 11 Sha'ban 1437<br>18 May 2016 |
| **THRU:** | **Afshan Ali, MD, MBA**<br>Chairperson, Research Ethics Committee<br>Office of Research Affairs | **REF:** | ORA/0807/37 |
| **FROM:** | **Rana Moshimany, Pharm D, CCRP**<br>Member, Research Ethics Committee<br>Office of Research Affairs | | |
| **SUBJECT:** | **Project # 2161 103**<br>Application of the Dual-Route Model in Exploring Dyslexias and Dysgraphias in Arabic Speaking Adult with Aphasia: Clinical and Theoretical Implications | | |

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The above-referenced proposal was reviewed expideitely by the Research Ethics Committee (REC) on 10 May 2016. It is my pleasure to inform you that the REC has recommended the proposal, waiver of informed consent and the data collection sheet for approval as submitted; and I would like to take this opportunity to congratulate you on behalf of the Research Advisory Council.

Please be informed that in conducting this proposal, the Investigators are required to abide by the rules and regulations of the Government of Saudi Arabia, KFSH&RC, and the RAC. Further, you are required to submit a Progress/ Final Report by **10 April 2017**; so it can be reviewed by the Committees without lapse of approval. The approval of this proposal will automatically be suspended **10 May 2017**, pending the acceptance of the Report. **You also need to notify the ORA as soon as possible in the case of:**

- any amendments to the project
- termination of the study
- any event or new information that may affect the benefit/risk ratio of the proposal.

# EXPEDITED REVIEW APPROVAL

To: Maha Aldera

CC: There are no items to display

Re: Study# Pro00006350
Application of the Dual-Route Model in Exploring Dyslexias and Dysgraphias in Arabic Speaking Adults with Aphasia: Clinical and Theoretical Implications

Study Expiration Date: 4/14/2017

This is to advise you that the above Study has been presented to the Institutional Review Board for expedited review.

Please be reminded that all modifications to approved projects must be reviewed and approved by the Institutional Review Board before they may be implemented. Any changes to this protocol must be submitted for IRB approval before initiated.

All serious adverse events and unexpected adverse events must be reported to Institutional Review Board within seven days.

Please do not make any changes to the IRB approved consent without approval of the IRB. Only the IRB stamped approved consent should be used.

If your study meets the definition of a qualifying study that meets the FDAAA 801 definition of an "applicable clinical trial", you are responsible for ensuring that the trial has been registered properly on the Clinical Trials.gov website prior to the enrollment of any subject.

"Applicable clinical trials" generally include controlled clinical investigations, other than phase 1 clinical investigations (with one or more arms) of FDA-regulated drugs, biological products, or devices, that meet one of the following conditions:

- The trial has one or more sites in the United States
- The trial is conducted under an FDA investigational new drug application or investigational device exemption
- The trial involves a drug, biologic, or device that is manufactured in the United States or its territories and is exported for research

For complete statutory definitions and more information on the meaning of "applicable clinical trial," see Elaboration of Definitions of Responsible Party and Applicable Clinical Trial (PDF).

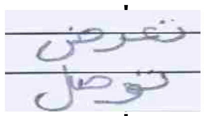
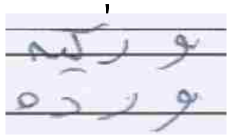
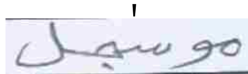
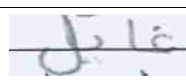
This study has been reviewed and approved via expedited review on 4/15/2016.

HIPAA waiver granted.

## Appendix 4

## Error Types

| | | |
|---|---|---|
| **Word errors** | Substitutions | Substituting one letter or more than one letter |
| | Omissions | Deleting one letter or more than one letter |
| | Movement | Changing the position of one letter |
| | Addition | Inserting one letter or more than one letter to the target word |
| | Compound | Making more than one type of error |
| **Lexical errors** | Morphological | Errors that are related morphologically and semantically to the target word |
| | Semantic | Substituting the target word with another word related semantically to the target word. |
| | Visual | Visually looks similar to the target word and confusion of letter-shape similarities. |
| | Phonological | Errors sound phonologically similar to the target word. |
| | Regularization | Errors are caused because of lack of mastery of the spelling rules of Arabic. |
| | Other | Errors resulted in real words or non-words not related to the target stimuli. |

| Case! ! | Example! | Target!stimuli! | Type!of!Error! |
|---|---|---|---|
| ! 1416 ! |  | تعا# "ةً<br>تـ !!صـة" | Omission!of!one! letter! |
| ! 0716! ! |  | ! صعـ! | Substitution! |
| 0916! ! ! |  | قة"# ! | Morphological! |
| ! 0616! ! ! |  | قبة$<br>! "مـ$<br>! | Other:! Words! NonDwords! |
| 0916! ! ! |  | ! مُسجـ! | Regularization! |
| ! 1416! ! |  | غالي! | Exchange! |