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Investigating the Influence of Phonotactic Probability on Spoken Word Recognition in Arabic

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***Abstract*—Evidence from English suggests that high phonotactic probability exerts facilitative effects on spoken word recognition. However, when lexical representations are activated in a Lexical Decision task, a reversed pattern of results is observed. That is, high phonotactic probability nonwords produce longer reaction times. In the present research, the influence of phonotactic probability on spoken word recognition in Arabic was examined using an auditory Lexical Decision task. In contrast to clear phonotactic probability effects in English, no effects of phonotactic probability on spoken word recognition in Arabic have been observed. We posit that some characteristics in Arabic morphology can impose processing demands that can diminish effects of phonotactic probability.**

***Index Terms*—first language processing, phonotactic probability, speech**

I. Introduction

Phonotactic probability refers to the likelihood of occurrence of phonological segments and sequences of phonological segments in words in a given language (Storkel et al., 2006; Storkel & Hoover, 2010; Vitevitch & Luce, 2005). The effect of phonotactic probability on different aspects of spoken language learning and processing has been shown to be robust, evident in infants, children, adults, and L2 learners. However, phonotactic probability studies have predominantly been conducted in Indo-European languages, particularly English. Nevertheless, other languages, especially those from different language families, possess dissimilar phonological and morphological systems which can directly impact how phonotactic probability knowledge is represented and processed. Consequently, drawing generalizable and universal conclusions regarding the representation and processing of phonotactic knowledge without examining phonotactic probability effects on languages that differ phonologically and morphologically can be challenging.

Therefore, the aim of the present study is to investigate phonotactic probability effects on spoken word recognition in the Arabic language. Arabic is a Semitic language, and its word formation follows different mechanisms compared to those adopted by Indo-European languages. Studying Arabic will provide insight into the universality of phonotactic probability effects and whether they operate based on the same mechanisms cross-linguistically. Dissimilar, or a lack of, phonotactic probability effects in Arabic may indicate that observed phonotactic probability effects in other languages are language-specific and are influenced by the phonological and morphological structure of the language. Such findings will have important implications for theories and models of the representation and processing of phonotactic probability.

II. Literature Review

Seminal work by Jusczyk and colleagues provided evidence that sensitivity to phonotactic patterns develops very early in the process of L1 acquisition. English-learning infants as young as nine months old prefer to listen to words that meet the phonotactic constraints of their L1 English but not Dutch language. Conversely, Dutch infants showed a similar pattern of preferring words that meet the phonotactic constraints of Dutch rather than English (Jusczyk et al., 1993). Additionally, American nine-month-old infants also prefer to listen to high phonotactic probability nonwords more than low phonotactic probability ones in their native language (Jusczyk et al., 1994). Interestingly, this sensitivity is utilized in lexical segmentation (Mattys & Jusczyk, 2001). Moreover, eighteen-month-old infants found learning object labels easier when these labels were phonotactically legal than when they were illegal (Graf Estes et al., 2011). Infants' sensitivity to phonotactic patterns has also been demonstrated in languages other than English and Dutch, including French, Turkish, Catalan, Japanese, and Hungarian (See Sundara et al., 2022, for a meta-analysis).

Likewise, the influence of phonotactic probability is evident in children, impacting both word recognition and production (Macroy-Higgins et al., 2014; Zamuner, 2009). Macroy-Higgins et al. conducted a study to investigate if toddlers' ability to detect mispronunciations is influenced by phonotactic probability. They discovered that 2-year-olds were more adept at detecting mispronunciations in high phonotactic probability words compared to low phonotactic probability ones. The researchers concluded that phonotactic probability directly affects the phonological representations of words, suggesting that representations for low phonotactic probability words are underspecified.

By the same token, evidence of phonotactic probability effects on different aspects of speech processing in adults has also been demonstrated. Seminal work by Vitevitch and colleagues has revealed clear effects of phonotactic probability on both spoken word recognition and production (e.g., Vitevitch & Luce, 1998, 1999, 2005). Using a Lexical Decision (LD) task, Vitevitch and Luce (1999, Exp 3) showed that phonotactic probability had effects on spoken word recognition in English even when nonwords are used. That is, subjects were slower and less accurate when rejecting high phonotactic probability nonwords than low phonotactic probability ones. However, when nonwords were used in a spoken nonword repetition task, phonotactic probability had facilitative effects. In other words, subjects were faster and more accurate when repeating high phonotactic probability nonwords than low phonotactic probability ones (Vitevitch & Luce, 2005).

Moreover, lexical acquisition appears to be facilitated by phonotactic probability in both children and adults. Children's acquisition of new words is influenced by low phonotactic probability (Storkel & Rogers, 2000; Storkel, 2001). Additionally, research suggests that phonotactic probability can enhance lexical access in children with specific language impairment during spoken word recognition (Quémart & Maillart, 2016). However, these phonotactic probability effects were not evident in children with cochlear implants, suggesting that these individuals may lack the ability to leverage phonotactic probability for word learning.

Similarly, adults' word learning shows similar facilitative effects of phonotactic probability. In a story context, Storkel et al. (2006) exposed adults to 16 nonwords paired with novel objects. Learning was measured in a picture naming task after different numbers of exposures. They found that adults learned a higher number of low phonotactic probability nonwords than high phonotactic probability ones. This led the authors to conclude that low phonotactic probability helps trigger new learning by enhancing subjects' ability to notice the difference between the new item and other lexical representations in the lexicon. Interestingly, biphone frequency (i.e., one measure of phonotactic probability with the other measure being positional frequency) alone can also enhance adults' recall of nonwords when neighborhood density is controlled (Thorn & Frankish, 2005).

More recently, however, research has taken new directions in studying the effects of phonotactic probability. These include effects on cognitive processes such as decision making (Vitevitch & Donoso, 2012), learning a foreign language (Luef & Resnik, 2023), learning in ambiguous cross-situational contexts (Dal Ben et al., 2022), and learning in noisy conditions (Han et al., 2016). Not all of these studies found facilitative effects of phonotactic probability. For example, Dal Ben et al. hypothesized that cross-situational word learning can introduce ambiguity, which may prevent subjects from relying solely on phonotactic probability in novel word learning. They presented native speakers of Brazilian-Portuguese with novel words paired with novel objects, where all the items had high phonotactic probability but with slight variations. Unlike most studies in the literature that used both positional segment frequency and biphone frequency to determine phonotactic probability, Dal Ben et al. solely used biphone frequency as a measure. Despite the slight variations in phonotactic probability (Dal Ben et al., 2022, p. 2) among the items, they found no effect of phonotactic probability on word learning, suggesting that factors like cross-situational learning may impede the effects of phonotactic probability.

Han et al. (2016) examined if background noise can modify the effects of phonotactic probability on word learning in adults. Nonwords that varied in phonotactic probability were paired with novel objects and trained in noisy conditions. A picture naming task was used to measure word learning. In contrast to the clear effects of phonotactic probability in quiet conditions found in Storkel et al.'s (2006) study, Han et al. (2016) found no effects of phonotactic probability on word learning in noisy conditions. These findings introduce yet another factor that can diminish the impact of phonotactic probability.

Learning context is not the only factor that can diminish phonotactic probability effects. Other lexical characteristics can play the same role. For example, it has been shown that for phonotactic probability effects to apply, it has to be either convergent (in children) or divergent (in adults) with phonological neighborhood density (PND). PND equals the number of words that can be created from a single word by virtue of one phoneme substitution, addition, or deletion (Vitevitch & Luce, 1999). For example, Hoover et al. (2010) studied phonotactic probability and PND effects on word learning in 3-5-year-old children. Using a picture naming task as a measure of learning, they found that novel words were easier to learn when phonotactic probability and PND converged. That is, Low phonotactic probability/Low PND words were easier to learn than Low phonotactic probability/High PND words. Similar findings were also reported in children with Language Impairment (McKean et al., 2014) and Dutch-speaking typically developing children (van der Kleij et al., 2016).

However, adults' word processing does not seem to necessitate such interaction between phonotactic probability and PND (Storkel et al., 2006). Storkel et al. found that phonotactic probability and PND influenced word learning differently, with a high phonotactic probability disadvantage and a high PND advantage. They suggested that, unlike studies on word recognition and production where a high probability advantage was observed, novel word learning requires triggering as a first step. This triggering is significantly aided by low phonotactic probability because low phonotactic probability novel words are easier to notice as they are less word-like. Consequently, they will trigger learning more than high phonotactic probability novel words (ibid).

How do these developmental changes in the effects of phonotactic probability take place? One argument is that phonotactic probability indexes a sub-lexical phonological representation, whereas PND indexes a lexical representation, and these two levels can be processed independently in adults (Vitevitch & Luce, 1999). Conversely, McKean et al. (2014) argued that children's phonotactic knowledge (i.e., phonological representation) is not fully developed. Therefore, they tend to rely on both phonological and lexical representations simultaneously, hence the converging effect of phonotactic probability and PND on word learning in children.

Not only do sub-lexical phonotactic effects and lexical PND effects undergo developmental changes, but PND effects have also been shown to exhibit different patterns in different languages in both spoken word recognition (cf., Luce & Pisoni, 1998; Vitevitch & Rodríguez, 2005) and production (cf., Vitevitch, 2002b; Vitevitch & Stamer, 2006). For example, it has been consistently shown that English words with dense PND are recognized more slowly and less accurately than words with sparse PND. This was attributed to competition effects amongst similar words (Luce & Pisoni, 1998). However, the opposite effect has been observed in other languages including Spanish (Vitevitch & Rodríguez, 2005) and Russian (Arutiunian & Lopukhina, 2020). Vitevitch and Rodríguez (2005) tested effects of PND on spoken word recognition in Spanish using the LD task. In the LD task, participants listen to spoken stimuli and decide as quickly and accurately as possible whether the stimulus is a real word or a nonword. They found that, unlike the pattern observed in English, PND had a facilitative effect in Spanish. In other words, Spanish words with dense PND were recognized more quickly and accurately than words with sparse PND. More recently, the same pattern in Spanish was also found in Russian (Arutiunian & Lopukhina, 2020).

To summarize, evidence suggests that phonotactic probability effects undergo developmental changes by gradually diverging from PND effects (Hoover et al., 2010; Storkel et al., 2006). Additionally, these effects may be influenced by factors such as background noise and learning context (Han et al., 2016; Dal Ben et al., 2022). Moreover, the pattern of PND effects, which phonotactic probability effects interact with, seems to be language-specific (Arutiunian & Lopukhina, 2020; Luce & Pisoni, 1998; Vitevitch & Rodríguez, 2005). Recent research has shown that a trained network successfully classified Maltese language nouns into their origin languages (i.e., Tunisian or Italian) based on phonotactic patterns (Nieder & Tomaschek, 2023). These findings suggest potential cross-linguistic differences in phonotactic probability effects on spoken word recognition, especially in languages with distinct morphological characteristics. Therefore, investigating phonotactic probability effects in other languages, such as Arabic, is crucial. Arabic differs morphologically from languages like English and Dutch, where phonotactic probability effects have been extensively studied. In their review titled "Phonotactics in Spoken Word Recognition" Vitevitch and Aljasser (2021) suggested that examining a language with significant differences from English, such as Arabic, would provide a robust test of how phonotactic probability influences processing across languages.

III. Methodology

If phonotactic probability effects are rooted in the morphological structure of the language, we would then expect to find dissimilar effects when comparing these effects between a Semitic morphologically non-concatenative language like Arabic and a concatenative language like English. This is because phonotactic probability has been determined based on either one or both of two measures in the literature: positional segment frequency and biphone frequency. Positional segment frequency refers to the probability of a given phoneme occurring in a specific position (e.g., the probability of /k/ appearing word initially as in 'kill', while biphone frequency refers to the probability of a given phoneme preceding or following another phoneme (e.g., the probability of /k/ followed by /ɪ/ as in the same word 'kill') (Jusczyk et al., 1994).

These measures are closely related to the morphological structure of the language, particularly word formation and syllable structure. For example, while the syllable in English allows zero onset (e.g., VC as in *eat* /i:t/) (Roach, 2009), onset is mandatory in Arabic syllables (Holes, 2004). Therefore, word initial positional segment frequency for Arabic vowels will always be zero. Moreover, another restriction in Arabic concerns consonant clusters. Whereas English accepts up to three consonants in onsets (e.g., street), Arabic does not allow consonant clusters word initially. This restriction directly impacts the biphone frequency of consonants in Arabic.

Another crucial factor that contributes to the complexity of the phonotactic system in Arabic is its unique word formation strategy. This strategy sets it apart from most languages, especially Indo-European ones. In English, for instance, words are formed concatenatively, where suffix morphemes are added to the stem to create new words, like 'teacher' and 'teaching' derived from the root 'teach'. In contrast, Arabic forms words non-concatenatively by combining a consonantal root with a vowel pattern (Wright, 1995). For instance, the Arabic word /taʕli:m/ 'teaching' is formed by integrating the three consonants of the root [ʕlm] with the pattern [ta- - i:-]. These distinctions between Arabic and other languages, particularly those studied for phonotactic probability effects, highlight the need to investigate these effects in Arabic to ascertain their universal applicability in language processing.

The aim of the present study is to investigate phonotactic probability effects on spoken word recognition in the Arabic language. Examining these effects in Arabic can provide two important insights: First, replicating similar cross-linguistic evidence of the influence of phonotactic probability on spoken word recognition will increase the generalizability of previous findings despite differences in phonological and morphological structures. On the other hand, different patterns, or lack, of effects, will indicate that facilitative phonotactic probability effects are not cross-linguistically valid but rather reflect certain characteristics of the language in question.

A. Research Question

Against this background, we endeavour to answer the following research question:

Does phonotactic probability, as represented by positional segment frequency and biphone frequency probabilities, separately or in combination, impact the speed and accuracy of spoken word recognition in Arabic?

B. Participants

Thirty-three native Arabic speakers voluntarily participated in the experiment. The participants were college students, all of whom were male, with an age range of 19-23 years old and a mean age of 21 years old. None of the participants reported any history of speech or hearing problems.

C. Instrument

One of the widely used paradigms in psycholinguistics, and specifically in spoken language recognition, is the Auditory Lexical Decision (ALD) task (Goldinger, 1996). In this task, participants provide lexical judgments or decisions (i.e., words or nonwords) of aurally presented stimuli. One advantage of this task is that it allows for the examination of spoken language processing in both real words and nonwords. This enables the exploration of both lexical (using real words) and sub-lexical (using nonwords) representations (Vitevitch & Luce, 1998, 1999). This is particularly crucial for the current investigation as we aim to investigate the effects of phonotactic probability, which primarily pertains to sub-lexical representations.

Another advantage of using the ALD task in the present study is that it has been used to study phonotactic probability effects in other languages including English (e.g., Vitevitch & Luce, 1999, Exp 3), Dutch (Strauß et al., 2022) and Italian (Bracco et al., 2015). Therefore, any observed effects of phonotactic probability or lack thereof in the current study should not be task effects. How lexical decisions of nonwords probe phonotactic probability effects is clearly captured in the following quote from Vitevitch and Luce (1999):

> Because the lexical decision task necessitates participants to differentiate between words and nonwords, the greater the number of words activated in memory, the slower the nonword response. Therefore, we anticipate a reversal of the results pattern noted in the shadowing and same–different matching tasks: high probability/density nonwords in the lexical decision task should elicit longer reaction times than the low probability/density stimuli. (p. 385)

Hence, if phonotactic probability exerts effects on spoken word recognition in Arabic similar to those in English, we predict that high phonotactic probability nonwords in the current study will take more time and will be less accurate to reject than low phonotactic probability nonwords. Different patterns of results will reveal that phonotactic probability (similar to PND) does not affect the processing of spoken words in the same way cross-linguistically.

D. Materials

A set of 40 trisyllabic nonwords was constructed following word formation mechanisms in Arabic, which involve mapping consonantal roots into vowel patterns. To prevent the influence of real Arabic roots on processing, only nonexistent Arabic roots were utilized. These were generated by substituting one consonant in actual Arabic roots. For instance, the last consonant /m/ in the real root /qdm/ was replaced with /b/ to create the nonexistent root /qdb/. These nonexistent roots were then combined with the same noun pattern to create 40 nonwords (e.g., /taqadbub/). By utilizing only one pattern type, any potential effects of pattern type and frequency on processing were eliminated. This method of stimuli creation offers several advantages in terms of controlling variables known to impact spoken word processing. By utilizing nonwords instead of real words, we eliminate certain lexical variables that could potentially bias results, such as word frequency and PND. Additionally, we were able to control for other factors known to influence processing, such as word length in terms of syllables and phonemes (Pitt & Samuel, 2006), as well as nonword onset (Vitevitch, 2002a). All nonwords in our set shared the same onset (/ta-/), and the critical nonword point was consistently after the fifth phoneme across all items.

Calculations of phonotactic probability for all 40 nonword stimuli were conducted using the web-based Arabic phonotactic probability calculator developed by Aljasser and Vitevitch (2018). This tool offers frequency-weighted estimates for individual phonemes in a sequence as well as biphone co-occurrence probabilities, utilizing a lexicon based on the arTenTen corpus (Arts et al., 2014). The calculator outputs the sum of positional phoneme probabilities (PPP) and the sum of biphone probabilities (BP) for each entry (i.e., nonword), which were instrumental in determining the phonotactic probability of the stimuli in our experiment. The utilization of a calculator that provides estimates for both PPP and BP is crucial for our study, as previous research has shown discrepancies in the consideration of these measures (Vitevitch & Luce, 1999; Steffman & Sundara, 2024). Moreover, insights from studies on the Italian language highlight the varying importance of different transitional probabilities within BP, emphasizing the significance of incorporating both measures to comprehensively explore phonotactic probability.

The 40 nonwords were divided into high and low PPP and BP conditions. The average sum of PPP and BP was 0.9714 and 0.1662, respectively, for the high PPP and BP nonwords and 0.0946 and 0.1509, respectively, for the low PPP and BP nonwords. Both PPPs and BPs were significantly higher in the high conditions than in the low conditions, $p < 0.001$.

For the ALD task, 40 real Arabic words were included. These words were matched to nonwords in terms of length (i.e., in syllables and phonemes) and initial phoneme. The total set of 80 stimulus items (40 nonwords and 40 real words) was spoken by a male native Arabic speaker at a normal pace in a language lab booth. Recordings were captured using a Beyerdynamic microphone sampling at a frequency of 44.1 kHz (16-bit resolution) and then stored on a computer disk. Each stimulus item was edited using Audacity, with an initial silence of 50ms in all files.

E. Procedure

Participants were tested individually in a quiet room. Each participant was seated in a relaxed position in front of a 19-inch computer screen equipped with a set of Beyerdynamic DT-100 headphones. The experiment was implemented in E-prime (Schenider et al., 2002). Before running the experiment, participants were instructed that they will listen to spoken stimuli and that their task is to judge by pressing the relevant keyboard button if each spoken stimulus is an existing word in Arabic or not. The same instructions appeared on the computer screen in Arabic. This was followed by 6 practice trials (three words and three nonwords). These trials were used to familiarize the participants with the task and were not included in the final data analysis. After the practice trials, participants' questions were answered. Upon running the experiment, each participant was then presented with the set of 80 randomly presented items at a comfortable listening level over the Beyerdynamic DT-100 headphones. The participants responded as quickly and accurately as possible by pushing the appropriately labeled button. 1500 ms separated each response and the presentation of the next item. RT was measured from the onset of the stimulus file to the onset of the participant's response. In addition to RTs as a dependent variable number of errors was the second dependent variable. An error is when a subject decides that a nonword is a real Arabic word.

IV. Results

Three participants were excluded from the analysis due to experimental errors; the final set comprised 30 participants.

A. Effect of PPP and BP and Their Interaction on Accuracy

Analysis was started by calculating the accuracy rate for each condition. Eprime data file assigns the value 1 to a correct response when the subject presses the correct "nonword" button and the value 0 to each incorrect response when the subject presses the wrong "word" button instead. The sum of these scores for each nonword was then divided by the number of subjects in each condition to calculate the mean correct response for each nonword. Mean percentage correct with standard deviation (SD) for each condition are shown in Table 1.

Table 1
Descriptive Statistics for Accuracy Percentage by PPP and BP

Dependent Variable: Accuracy percentage			
PPP	BP	Mean	Std. Deviation
High	High	97.0000	2.44949
	Low	97.4615	3.20456
	Total	97.3000	2.90372
Low	High	95.8462	3.36269
	Low	97.8571	2.26779
	Total	96.5500	3.11997
Total	High	96.2500	3.05864
	Low	97.6000	2.85436
	Total	96.9250	2.99904

The descriptive statistics for accuracy percentage reveal that the mean accuracy scores are generally high across all conditions, with slight variations depending on the combination of PPP and BP. Overall, the total mean accuracy across all conditions is 96.93% (SD = 2.99, N = 40), indicating consistently high performance across different probability conditions, with only minor variations. This suggests that while there is some variation in accuracy based on PPP and BP, the differences are not substantial.

A two-way Analysis of Variance (ANOVA) was used to evaluate the effects of PPP, BP, and their interaction on accuracy percentage. This method enables the examination of the main effects of each independent variable and their combined effect on the dependent variable. Through the implementation of two-way ANOVA, we aim to ascertain the individual and combined significance of each probability factor on accuracy percentage, as well as to investigate how these factors interact to affect performance outcomes.

The results from the two-way ANOVA indicate that neither PPP nor BP, nor their interaction, have a statistically significant effect on accuracy percentage. The main effect of PPP is not significant ($F(1, 36) = 0.145$, $p = .706$), suggesting that variations in PPP do not meaningfully impact accuracy. Similarly, the effect of BP is also not significant ($F(1, 36) = 1.537$, $p = .223$), indicating that changes in BP alone do not significantly influence accuracy percentage. Furthermore, the interaction between PPP and BP is not significant ($F(1, 36) = 0.604$, $p = .442$), meaning that the combined effect of these variables does not contribute to a significant change in accuracy. The low R Squared value of .071 (with an Adjusted R Squared of -0.006) suggests that the model explains only a minimal portion of the variance in accuracy percentage. This indicates that other factors not included in the model may play a more substantial role in determining accuracy.

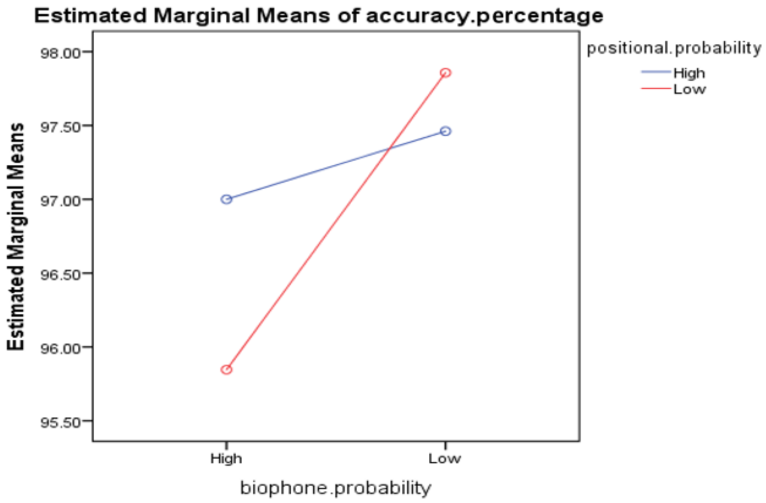

Figure 1. Estimated Marginal Means of Accuracy Percentage

B. Effect of PPP and BP and Their Interaction on Reaction Time

TABLE 2
DESCRIPTIVE STATISTICS FOR RTS IN MS BY PPP AND BP

Dependent Variable: RT

PPP	BP	Mean RTs	Std. Deviation
High	High	1348.1529	70.27578
	Low	1344.7115	68.26228
	Total	1345.9160	67.12238
Low	High	1358.0969	55.62888
	Low	1370.2514	73.26251
	Total	1362.3510	60.70265
Total	High	1354.6165	59.47884
	Low	1353.6505	69.23991
	Total	1354.1335	63.71317

Mean RTs in milliseconds (ms) with standard deviation (SD) for each condition are shown in Table 2. The descriptive statistics show that RTs are fairly consistent across the different combinations of PPP and BP. Overall, the RTs do not vary greatly between conditions, with the total mean RT being 1354.13 ms ($SD = 63.71$) across all items ($N = 40$). The relatively small differences in means and standard deviations suggest minimal impact of PPP and BP on RT.

A two-way ANOVA was conducted to investigate the effects of PPP and BP, as well as their interaction, on RT. The primary goal of this analysis was to determine whether these independent variables, either individually or in combination, significantly influence the dependent variable, RT. By analyzing the variance within and between groups, the two-way ANOVA provides insights into the main effects and any potential interaction effect between PPP and BP on the speed of word processing.

The results of the ANOVA analysis indicate that the overall model did not significantly explain the variance in RT ($F(3, 36) = 0.266$, $p = .850$, $R^2 = .022$). None of the independent variables: PPP ($F(1, 36) = 0.666$, $p = .420$), BP ($F(1, 36) = 0.040$, $p = .842$), or their interaction ($F(1, 36) = 0.129$, $p = .722$) had a statistically significant effect on RT. The intercept was significant ($p < .001$), which is expected, but the low R^2 value (0.022) and the negative Adjusted R^2 (-.060) suggest that the model explains only a small fraction of the variance in RT, and it is not a good fit for the data.

In summary, the independent variables examined do not seem to have a significant effect on RT, and the overall model lacks explanatory power for the observed data. This indicates that there may be other unaccounted factors that play a more significant role in determining RTs.

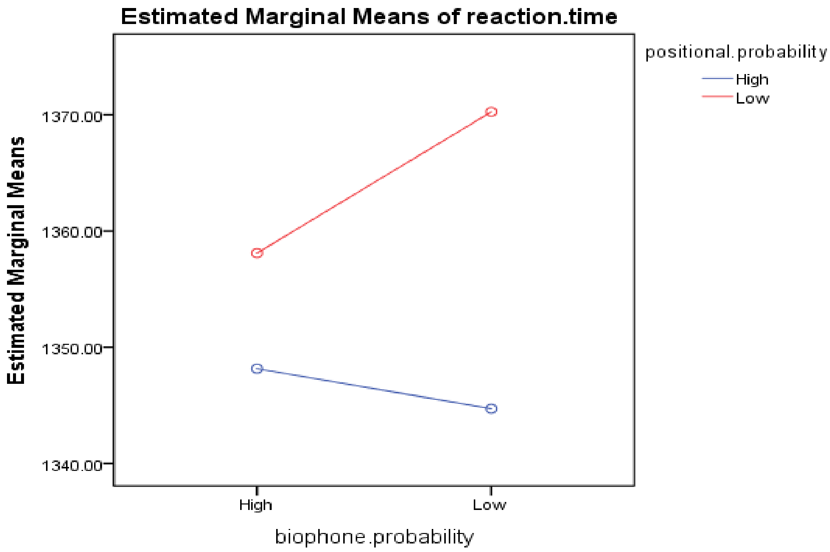

Figure 2. Estimated Marginal Means of Reaction Time

V. Discussion

Phonotactic probability effects on spoken word recognition have been well established in Indo-European languages like English and Dutch. The current study sought to answer an important question: does phonotactic probability influence spoken word recognition in similar ways cross-linguistically, particularly in a language that differs considerably? For this purpose, the effect of phonotactic probability on spoken word recognition in Arabic was investigated. This study is - to the best of our knowledge- the first to examine phonotactic probability effects on spoken word recognition in Arabic. Our findings showed no effects of phonotactic probability. High phonotactic probability nonwords were rejected as fast and as accurately as low phonotactic probability nonwords. This pattern of results is different from the pattern observed in English. In English, nonwords with low phonotactic probability are rejected more quickly than nonwords with high phonotactic probability (Vitevitch & Luce, 1999, Exp 3).

What could be the cause behind this pattern of results in Arabic? One potential reason is that the great morphological complexity within a language produces more processing demands that diminish the influence of phonotactic probability. Recall that PND effects on spoken word recognition also differ cross-linguistically. Whereas PND has competitive inhibitory effects on spoken word recognition in English, it has facilitative effects in Spanish (cf., Luce & Pisoni, 1998; Vitevitch & Rodríguez, 2005). Vitevitch and Rodríguez reasoned that since Spanish typically has longer words than English, the difference in length required different processing, which resulted in reverse effects of PND in Spanish. Indeed, cross-linguistic differences in processing mechanisms and strategies are observed not only in spoken word recognition but also in the processes preceding it. For example, English speakers have been found to adopt different lexical segmentation strategies from Japanese speakers (cf., Cutler & Norris, 1988; Otake et al., 1993).

However, consider that nonwords in the current investigation are longer than those used in previous studies reviewed above. Pitt and Samuel (2006) found that longer words produced more lexical activation than shorter words. In the current study, it is possible that such greater activation may have prolonged RTs across items producing a ceiling effect. This explanation has considerable appeal. However, it should be treated with caution. That is, studies investigating the role of PND found that long words produce the same inhibitory competitive effect as short words in English (Vitevitch et al., 2008) despite a contrastive facilitative effect of PND in Spanish (Vitevitch & Rodríguez, 2005).

Taken together, given the cross-linguistic evidence of different processing strategies in spoken word recognition and the morphological complexity of Arabic, it is possible that Arabic speakers rely on different processing strategies that weaken the influence of phonotactic probability. A case in point is the pivotal role of the root in processing in Arabic spoken word recognition as opposed to stem-based processing in English. All our nonword stimuli had nonexistent roots, created by replacing the third consonant of real roots (e.g., the last consonant /m/ in the real root /qdm/ was replaced with /b/ producing the nonexistent root /qdb/). Empirical evidence shows that the root is the main processing unit in Arabic (Boudelaa & Marslen-Wilson, 2011, 2013, 2015; Aljasser, 2020), indicating that subjects likely rejected nonwords as soon as they noticed the absence of a real root (at the nonroot point, always at phoneme six). This reduced the impact of phonotactic probability, which requires processing of all phonemes in the target stimulus. Furthermore, using the same word pattern for target nonwords and real word fillers in the current experiment, thus unifying the morphosyntactic properties of the items (Wright, 1995), may have led subjects to rely more on semantic cues in root processing for their lexical decisions. This interpretation aligns with previous evidence highlighting the significant role of the root in Arabic spoken word recognition. Whether utilizing different stimuli with the nonword point at the last phoneme and employing various word patterns would yield different results remains an open question.

Using the same type of pattern across items was due to our desire to rule out effects of word patterns on processing. However, this imposed some constraints on the creation of our nonword stimuli by minimizing the difference, albeit significant, particularly in mean BP between the high and low conditions. One concern is that these subtle differences in phonotactic probability were not perceived by our participants. However, recent evidence suggests that subtle differences in phonotactic probability can facilitate speech segmentation (Dal Ben et al., 2021). This indirectly rules out subtle differences as a cause for the lack of phonotactic probability effect in the current study.

VI. Conclusion

Although phonotactic probability effects on spoken word recognition have been established in other languages, we did not find such effects in Arabic spoken word recognition. We hypothesize that the morphological complexity of Arabic is the main factor contributing to this absence of phonotactic probability effects in our study. Therefore, it can be concluded that the impact of phonotactic probability on spoken word recognition, akin to PND, varies across languages. These results present challenges to current models of spoken word recognition, suggesting the need for revising and expanding existing models to incorporate cross-linguistic factors that may modulate the influence of phonotactic probability in language processing.

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