www.czasopisma.pan.pl PAN www.journals.pan.pl

Archives of Acoustics Vol. **47**, No. 3, pp. 319–329 (2022), doi: 10.24425/aoa.2022.142006

Research Paper

Medial Vowel Temporal Acoustics in Arabic and Japanese Polysyllabic Words

Yahya ALDHOLMI

Department of Linguistics and Translation Studies
King Saud University
Riyadh, Saudi Arabia; e-mail: yaldholmi@ksu.edu.sa

(*received March 4, 2022; accepted May 27, 2022*)

The current study is dedicated to measuring vowel temporal acoustics (duration, durational difference, and durational ratio) in the medial position of mostly CVCVCV polysyllabic words in Arabic and Japanese, avoiding the asymmetries in vowel position, syllable structure, and coda consonant quantity (singleton versus geminate) observed in previous experiments. Twenty-nine (16 Arabic and 13 Japanese) participants were asked to use a carrier sentence to produce 60 polysyllabic (mainly CVCVCV) items that contrasted in vowel quantity (short versus long) and vowel quality (/a/, /i/, and /u/) at a normal speech rate. The results show that while short and long vowels are durationally distinct within a language, Japanese vowels are clearly longer than Arabic vowels, although the durational difference remains approximately the same between the two languages. The durational ratio of short-to-long vowel presents a new pattern that contrasts with that reported in earlier research. Specifically, Japanese long vowels in the medial position of polysyllabic words are twice as long as their short counterparts, while Arabic long vowels are more than twice as long. This shows that both vowel position and syllable structure must be considered when measuring vowel temporal acoustics or when structuring stimuli for perception experiments.

Keywords: temporal acoustics; vowel duration; durational difference; durational ratio; Arabic; Japanese.

1. Introduction

It has been long documented that vowel temporal acoustics (i.e. duration) is phonemic in Semitic languages such as Arabic, e.g. (Harris, 1942; Cantineau, 1956; Ferguson, 1957; Cowan, 1970; Al-Ani, 1970; Mitleb, 1984a; Alghamdi, 1998; Amir *et al.*, 2012; 2014; Ammar *et al.*, 2014; Kalaldeh, 2018; Almisreb *et al.*, 2016). However, vowel duration across Arabic dialects such as Egyptian, Iraqi, Jordanian, Saudi, Libyan, Moroccan, Palestinian, Saudi, Syrian, and Tunisian, as well as Modern Standard Arabic (MSA), exhibit differences in vowel length that have been measured and documented in various studies, e.g. (Ahmed, 2008; Alghamdi, 1998; Almbark, Hellmuth, 2015; Al-Tamimi, Barkat-Defradas, 2003; Kalaldeh, 2018; Hassan, 1981; Kotby *et al.*, 2011; Mitleb, 1984a; Saadah, 2011). Measures of vowel duration from such studies have been used to address various research questions in both cross-language production and perception studies, e.g. (Hong, Sarmah, 2009; Lababidi, Park, 2016). One of the languages most frequently compared to Arabic is Japanese (Tsukada, 2009; 2010; 2011a; 2011b; 2012a; 2012b; 2013; Aldholmi *et al.*, 2021). This is likely due to the presence of identical short-long vowels, namely /a/, /i/, and /u/, in the phonological inventory of both languages, which facilitates comparison and reduces possible confounds.

Many of these studies share commonalities in their methods and data analysis. Specifically, the stimuli often consist of mainly *monosyllabic* CVC words or nonwords, e.g. (Alghamdi, 1998; Tsukada, 2010; 2012b; 2013; Zaltz, Segal, 2022), with a few studies also including CVCV or CVCVC items (Kotby *et al.*, 2011; Amir *et al.*, 2012; Ammar *et al.*, 2014). When vowel duration was either an acoustic or perceptual factor of comparison between Arabic dialects or between Arabic and Japanese (as well as some other languages), a discrepancy in the syllable structure (CVC versus non-CVC) has been observed, e.g. (Tsukada, 2011b; 2012a). Concomitantly, a discrepancy in vowel position, e.g. (CVC versus CVCV) has also appeared in some studies such as in (Ammar *et al.*, 2014) who used both C**V**CVCV and CVC**V**C with the first vowel being the target in the former and the second vowel in the latter. Word-, phrase- and sentence-final vowels are prone to shortening and lengthening in various ways. For instance, for words in isolation, Japanese word-final vowels are lengthened by approximately 30% compared to word-medial vowels (Sagisaka, 1984), whereas for declarative sentences, sentence-final vowels get shortened in prepausal positions (Takeda *et al.*, 1989). Other studies have reported lengthening or shortening effects on vowel duration in final position in Japanese words and sentences, e.g. (Mori, Erickson, 2008), indicating that despite the fact that Japanese is a mora-timed language, vowel duration is subject to lengthening and shortening depending on the type of utterance (word versus sentence) and the vowel position (medial versus final). Likewise, Arabic vowel duration is influenced by several factors, e.g. (De Jong, Zawaydeh, 2002) such as geminacy of the following consonant (Aldubai, 2015; Ferrat, Guerti, 2017; Hassan, 2002), as the two quantity-based phonemes (singletons and geminates) frequently alternate word-finally in monosyllabic Arabic CVC items in particular. Unfortunately, many studies that examined vowel duration in Arabic used seemingly minimal CVC pairs that did not only differ in vowel duration but in final consonant duration as well. For example, in several studies, e.g. (Tsukada, 2010; 2011a; 2011b; 2012a; 2012b; 2013) Tsukada used words like /riq/ "slavery" versus /riːq/ "salvia", /sin/ "tooth" versus /siːn/ "the Arabic letter S", /zir/ "button" versus /ziːr/ "large jar", /ħur/ "free" versus /ħuːr/ "beautiful women", which involve a final geminate in the first member of each pair, where the vowel is short (short vowel + long consonant), and a final singleton in the second member of each pair, where the vowel is long (long vowel + short consonant). That is, all short vowel items have the structure of CV**CC** while the long vowel items have the structure of C**VV**C, visually indicated in (Tsukada, 2012b) by an additional consonant placed between two parentheses as in /riq(q)/ "slavery", /zir(r)/ "button", and /ħur(r)/ "free".

Thus, there are four potential methodological concerns. First, comparison between vowels in different positions such as C**V**CVC versus CVC**V**C as in (Ammar *et al.*, 2014) is not ideal. Second, inconsistency in the number of syllables in the stimuli puts some vowels in CVC structure and others in CVCV or CVCVCVC structure as in (Kotby *et al.*, 2011). Third, short vowels in these studies occurred pre-geminately, which makes them less comparable to their long counterparts that occurred before singletons since geminacy has been shown to affect the preceding vowel, e.g. (Kawahara, 2015). For instance, Aldubai (2015) demonstrated that vowels that precede geminates tend to be shorter in Yemini Arabic. Fourth, the use of CVC in one language and CVCV in another, as in several studies comparing Arabic dialects or Arabic to Japanese and other languages, was not ideal.

Hence, the current study seeks to answer two research questions while avoiding all such abovementioned concerns: *1) What are the temporal acoustics of medial short versus long vowels in Arabic versus Japanese polysyllabic words?, 2) How are they similar or dissimilar to those of non-medial vowels found in previous experiments?* The present study differs from previous ones in that it examines the temporal acoustics (mainly the duration) of the medial (rather than the first or final) vowel in Arabic and Japanese, using polysyllabic words with no peripheral gemination, which were either not used or used jointly with monosyllabic words in some previous studies leading to a methodological asymmetry. If the methodological issues outlined above had any impact on the conclusions drawn from previous studies, we should expect our results to diverge from those previously reported. In addition to vowel duration, this study also reports on durational difference and sheds some light on the durational ratio of short-to-long vowels in both languages, as these two metrics have been occasionally referred to in some of the aforementioned studies.

2. Vowel temporal acoustics in Arabic: Experiment 1

The aim of the first experiment is to establish a baseline for duration and durational difference of short versus long Arabic vowels in medial position of polysyllabic words, a non-peripheral position that has been largely overlooked in the literature. Fifteen male and female native speakers of Arabic participated in this experiment. Each was instructed to produce a list of 60 selected Arabic CVC**V**CV versus CVC**V:**CV word pairs, for example /nab**a**ːta/ "grew" versus /nab**a**ːtu/ "plant", at a normal speech rate. More details are provided below.

2.1. Methodology

Sixty MSA CVCVCV words, of which 48 items were adopted with slight modification from (Aldholmi *et al.*, 2021), were used as stimuli in this experiment. The items contrast in vowel quantity (short versus long) and vowel quality (/a/, /u/, /i/) in the second syllable. As outlined above, although several previous studies examining contrasts in Arabic vowel length used monosyllabic (CVC versus CVːC) items, the decision here was to use a polysyllabic (CVCVCV versus CVCVːCV) structure instead. We targeted and varied the second vowel in each item in both experiments reported in this study. The target vowels are neighbored mostly by obstruents that vary in terms of voicing and place of articulation, although several studies have shown that voicing does not trigger lengthening in Arabic, see e.g. (Flege, Port, 1981; Mitleb, 1984b). Adjacent geminates were intentionally avoided for the reasons explained above.

Sixteen native speakers of Najdi Arabic (9 males and 7 females) participated in this experiment. All of the participants were undergraduate students (age, M = 23.4, SD = 2.1) at King Saud University (KSU) pursuing a Bachelor's degree in Arabic language and literature. Each participant was met in a quiet room on campus and asked to produce the stimuli at a normal speech rate using the carrier sentence /qultu/ "I said", as many previous studies have done, e.g. (De Jong, Zawaydeh, 2002). The participants were first given three minimal pairs, which were excluded from the actual experiment, to practice before they recorded the target stimuli. They were asked to listen to the first sentence they recorded from each condition (i.e. both in terms of vowel duration and vowel type) and use it as a model, an attempt to reduce the possible effect of any speech rate variations. The stimuli were recorded at 44 100 kHz, using Praat (Boersma, Weenink, 2022). All participants were asked to provide demographic information including gender and language details such as second language skills and potential language impairments. None of them reported extensive experience with Japanese or a history of hearing or speaking disorders or impairment.

2.2. Results and discussion

As shown in Fig. 1, Arabic long vowels are clearly longer than their short counterparts (M = 164, SD = 19 versus M = 62, SD = 15, respectively). Figure 2 provides further details for the difference between short and long vowels for each vowel type. Although the durations are generally similar, the low vowel /a/ appears to be longer than the other two. A repeated measures ANOVA was performed to test the difference between the two conditions for the two variables (length and type), and the result indicates that the

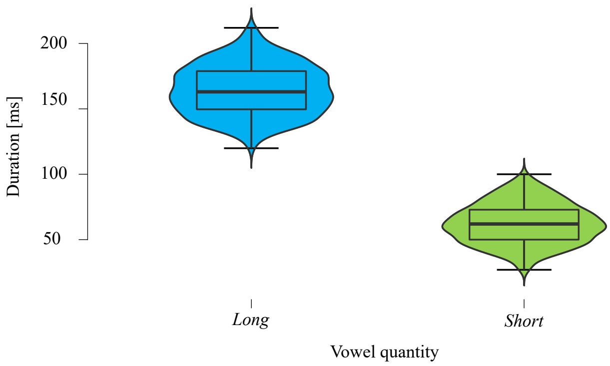

Fig. 1. Medial vowel duration in Arabic polysyllabic words, broken down by vowel quantity.

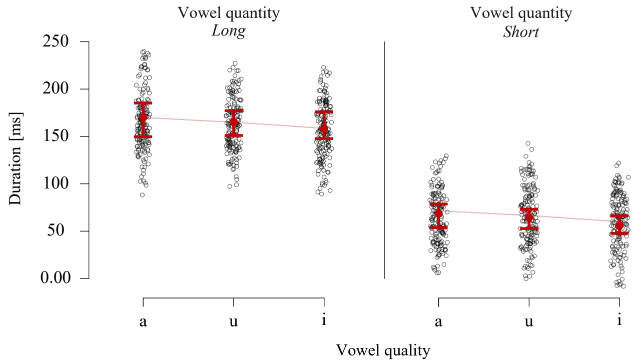

Fig. 2. Medial vowel duration in Arabic polysyllabic words, broken down by vowel quantity and quality.

difference is statistically significant for vowel length, $F(1,15) = 2455$, $p < 0.01$, $\omega^2 = 0.92$, and for vowel type, $F(1,15) = 2118$, $p < 0.02$, $\omega^2 = 0.39$, but the interaction between the two variables was not statistically significant.

After looking at each category (short versus long) individually, the durational difference was calculated by subtracting the duration of the short vowel from that of the long vowel in each (nearly) minimal pair for each participant, M = 102, SD = 15 (see Fig. 3). This difference is relatively smaller than the difference that can be calculated from the averaged short vowel duration (93 ms) and averaged long vowel duration (209 ms) documented in (Tsukada, 2013), 209 – 93 = 116. Note the marginally different method used to calculate the durational difference in our experiment as compared to that using duration means reported in (Tsukada, 2013). The durational difference in the current experiment was calculated by obtaining the durational difference for each of the two data points in a near minimal pair and then obtaining the mean of the durational differences. We have no access to the actual data from (Tsukada, 2013), but the two methods should lead to roughly the same values.

Table 1. Medial vowel duration and durational difference in Arabic polysyllabic words, broken down by vowel quantity.

	Duration		
	Difference	Short	Long
Mean	102	62	164
SD	15	15	19

Figure 3 and Table 2 depict durational differences for the three vowel types (/a-aː/, /u-uː/, /i-iː/). These show a similar pattern, with /a/ having a slightly larger mean, M = 105 (SD = 16), M = 100 (SD = 16), and M = 101 (SD = 15), respectively. A repeated measures ANOVA test was performed to test for the mean differences among the three vowels, the results of which show that the durational differences differed signifi-

Table 2. Medial vowel duration and durational difference in Arabic polysyllabic words, broken down by vowel quantity and quality.

Vowel quality	Duration								
	Difference			Short			Long		
	/a-aː/	/u-uː/	/i-iː/	/a/	/u/	/i/	/aː/	/uː/	/iː/
Mean	105	101	101	63	64	60	168	164	161
SD	17	15	15	15	15	15	21	18	18

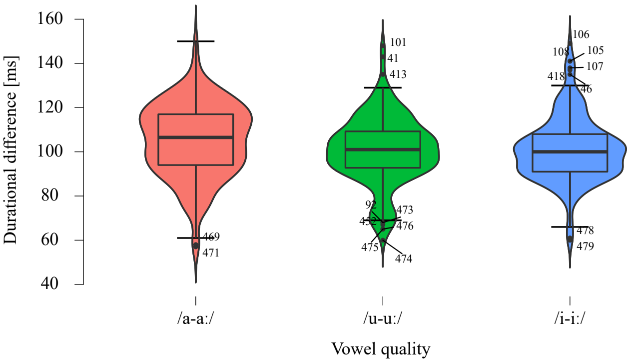

Fig. 3. Medial vowel durational difference in Arabic polysyllabic words, broken down by vowel quantity and quality.

cantly across the three vowels (sphericity assumed, $p = 0.286$), $F(2, 15) = 9.85$, $p < 0.001$, $\omega^2 = 0.20$. A pairwise comparison revealed that the difference lies between /a-aː/ and /u-uː/, $p < 0.001$, and between /a-aː/ and /i-iː/, $p < 0.003$, but not between /i-iː/ and /u-uː/, $p = 0.628$. This pattern is similar to that in (Tsukada, 2013). Although the author did not provide the average length for each vowel numerically, visual inspection of Fig. 1 – Panel A (p. 190) can inform us that the vowel /a-aː/ tends to be longer than the other two vowels. The difference between the low vowel /a-aː/ and high vowels /i-iː/ and /u-uː/ in terms of duration has been long noted not only in Arabic, e.g. (Mitleb, 1984b) but also in other languages such as English, e.g. (Klatt, 1976); universally, high vowels tend to be shorter than low vowels, a phenomenon referred to as "intrinsic vowel duration" (Maddieson *et al.*, 1996, p. 163). Different explanations have been offered, some of which are mechanically based while others are neurally based, or a combination of both, see, e.g. (Smith (1987) for an overview). However, this is beyond the scope of the current work.

The ratio of short to long vowel durations for MSA in the current study is roughly 0.38, which is relatively smaller than that (≈ 0.50) reported for Iraqi Arabic in (Al-Ani, 1970), for Kfar Kassem/Kfar Barra/Jaljulia dialects in Isreal (in which long vowels are twice long as short ones) in (Amir *et al.*, 2012), and for the Saudi dialect (calculated for three vowels as M = 0.44) in (Alghamdi, 1998), and noticeably smaller than that (= 0.65) reported for Jordanian Arabic in (Mitleb, 1984a). However, the durational difference ratio obtained here is similar to the ratio that can be calculated from the short versus long duration means reported in (Saddah, 2011) for Palestinian Arabic (0.39). Short and long vowel durations (and hence sometimes durational differences) clearly vary across dialects (Tsukada, 2012b), but the average ranges between 0.39 and 0.45 (although Jordanian has a ratio of 0.65), regardless of whether such values are literally reported in previous studies or can be calculated from the short and long vowel durations they documented. Short-long durations in MSA (produced by Jordanians) have been found to be similar to those in Palestinian Arabic as reported in (Saddah, 2011). Specifically, Kalaldeh (2018) found that MSA long vowels are more than twice the duration of MSA short vowels, and suggested that acoustic properties of Jordanian Arabic, a dialect that shares many phonetic features with Palestinian Arabic, have been carried over to MSA, causing the vowel duration in Jordanian MSA to resemble that of Palestinian Arabic.

3. Vowel temporal acoustics in Japanese: Experiment 2

Experiment 1 was conducted to investigate the temporal acoustics of short-long medial vowels (primarily, vowel duration, and secondarily, durational differences) in Arabic polysyllabic words. As stated before, Arabic shares three similar short-long vowels with Japanese. Therefore, Experiment 2 was conducted with the purpose of examining the temporal acoustics (duration and durational differences) of the same three short versus long medial vowels in Japanese polysyllabic words.

3.1. Methodology

As in Experiment 1, 60 items were selected for this experiment, all of which were adopted from an online pilot study that is not reported in this work. Similar to the stimuli in Experiment 1, most of the items were near minimal pairs with a CVC**V**CV versus CVC**Vː**CV polysyllabic structure, but a few items had a coda (CVCVCV**C** versus CVCVCV**ː****C**) and even fewer had an additional CV syllable (CVCVCV**CV**). This was necessary to come up with enough items that are as close as possible to the Arabic items in Experiment 1 in terms of being (nearly) minimal pairs and containing different types of consonants surrounding the target vowels. Thirteen native speakers of Japanese (6 males and 7 females) living in Tokyo produced the Japanese items, adhering to the same instructions and performing the same task as in Experiment 1. They were instructed to record the 60 words, for example /kaguru/ "go through" versus /kaguː-ru/ "cagoule hat", using the carrier phrase /wataʃi wa itta/ (in broad transcription) "I said". As in Experiment 1, they were asked to self-report demographic information to confirm that none of them speaks Arabic, with the exception of one female who stated that she can utter a very limited number of words that frequently appear in the media such as /salaam/. None had any issues with hearing or speaking.

3.2. Results and discussion

Figure 4 shows that Japanese long and short vowels differ in duration (M = 205, SD = 44 versus M = 103, SD = 31, respectively). A repeated measures ANOVA was performed to test the difference between the two conditions (short and long), which turned out to be statistically significant, $F(1,12) = 414.90$, $p < 0.01$, $\omega^2 = 0.97$. Figure 5 also shows the differences between short and long vowels but with details regarding vowel quality. The differences between the three types of vowel quality are also statistically significant, $F(1,12) = 13.75$, $p < 0.01$, $\omega^2 = 0.53$, but the interaction between the two variables was not statistically significant.

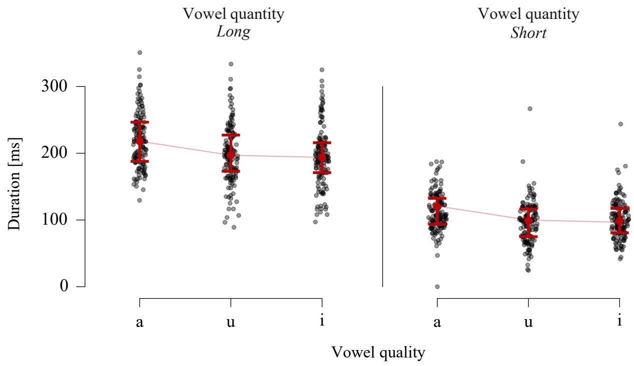

Fig. 5. Medial vowel durational difference in Japanese polysyllabic words, broken down by vowel quantity and quality.

Durational difference was calculated following the same procedure in Experiment 1 to find a durational difference of M = 102, SD = 16. Table 3 compares the means and SDs for short vowels, long vowels, and durational differences. As shown in Fig. 6 and Table 4, the durational differences for the first two vowel types show similar values (/a-aː/, /u-uː/, M = 107 (SD = 13), M = 103 (SD = 18)) with a slightly different value for

Table 3. Medial vowel duration and durational difference in Japanese polysyllabic words, broken down by vowel quantity.

	Duration		
	Difference	Short	Long
Mean	102	103	205
SD	16	31	44

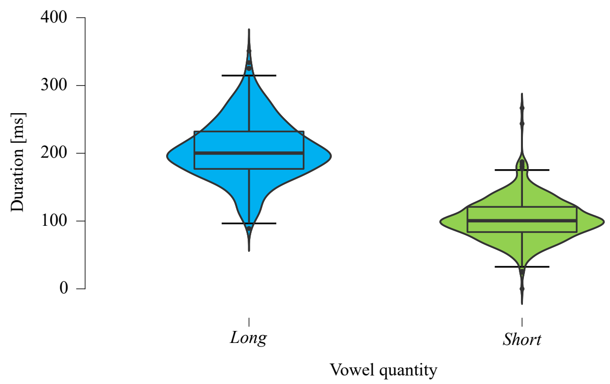

Fig. 4. Medial vowel duration in Japanese polysyllabic words, broken down by vowel quantity and quality.

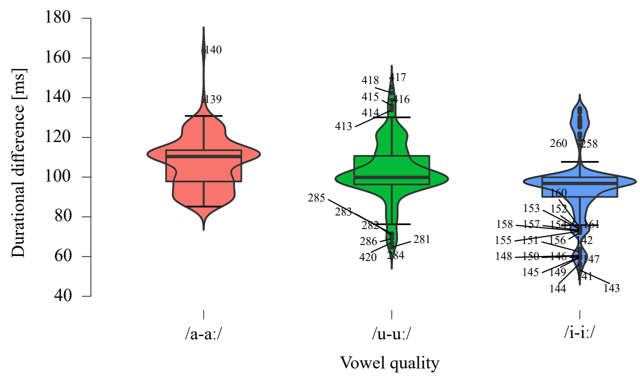

Fig. 6. Medial vowel durational difference in Japanese polysyllabic words, broken down by vowel quantity and quality.

Table 4. Medial vowel duration and durational difference in Japanese polysyllabic words, broken down by vowel quantity and quality.

Vowel quality	Duration								
	Difference			Short			Long		
	/a-aː/	/u-uː/	/i-iː/	/a/	/u/	/i/	/aː/	/uː/	/iː/
Mean	107	103	96	112	96	99	220	199	195
SD	13	18	14	29	31	29	40	43	44

the third type (/i-iː/, M = 96 (SD = 14)). A repeated measures ANOVA shows that the durational differences varied significantly across the three vowels, $F(2,12) = 22.25$, $p < 0.001$, $\omega^2 = 0.63$. A pairwise comparison reveals that the difference lies between /a-aː/ and /i-iː/, $p < 0.001$, between /a-aː/ and /i-iː/, $p < 0.013$, and between /a-aː/ and /u-uː/, $p < 0.01$.

In general, the front vowel /i/ (both short and long) is the shortest among the three vowels, and the durational difference between the short version and its long counterpart is the smallest among the three durational differences. The overall difference is relatively larger than the difference that can be calculated from the averaged short vowel duration (120 ms) and averaged long vowel duration (252 ms) reported in (Tsukada, 2013), 252 − 120 = 132. The durational ratio, which is roughly 0.50 in the current study, is also larger than that reported in previous studies, e.g. (Tsukada 2012a), a difference that will be discussed further later.

4. Overall comparison and discussion

Table 5 compares the main findings from the two experiments. This facilitates observation that short and long vowels are durationally different in both languages, a finding that has been well established in previous research, and that short and long vowels in Japanese have longer durations than those in Arabic. A repeated measures ANOVA test was performed to examine the effect of vowel quantity (short versus long) as a within-subject variable and the effect of language (Arabic versus Japanese) as a between-subject variable on duration. The test shows evidence that there is a statistically significant difference between short and long vowels, $F(1,27) = 1310.70$, $p < 0.001$, $\omega^2 = 0.98$, and between Arabic and Japanese, $F(1,27) = 67.33$, $p < 0.001$, $\omega^2 = 0.71$. The test also shows a statistically significant interaction between vowel quantity and language, $F(1,27) = 16.68$, $p < 0.001$, $\omega^2 = 0.37$. This interaction means that the difference between short and long vowels is not independent from the difference between Arabic and Japanese, or vice versa.

Table 5. Comparison between short versus long medial vowel duration in Arabic versus Japanese polysyllabic words.

	Duration			
	Short		Long	
	Arabic	Japanese	Arabic	Japanese
Mean	62	103	164	205
SD	15	31	19	44

Durational difference is strikingly identical in Arabic (precisely 101.8 rounded to 102) and Japanese (precisely 102.02 rounded to 102) (Table 6). Performing a repeated measures ANOVA test with language as a between-subjects variable finds no statistically significant difference between the durational difference in Arabic and Japanese, $F(1,27) = 0.003$, $p = 0.96$, $\omega^2 = 0.00$.

Table 6. Comparison between short versus long medial vowel durational differences in Arabic versus Japanese polysyllabic words.

	Durational difference	
	Arabic	Japanese
Mean	102	102
SD	15	16

The individual and combined findings from both experiments reveal several important points. First, despite the fact that the durations of short and long vowels in Arabic and in Japanese are distinct, durational difference does not seem to be a sufficient parameter to compare vowel duration in the two languages. The durational difference of Arabic is roughly double the value of 45 ms reported in (Mitleb, 1984a), but the durations he reported are not much larger or smaller than the ones we observe in the current study. Furthermore, the mean durations of short and long vowels in his study are 83 ms and 128 ms, respectively, (compared to 62 ms and 164 ms, respectively in the current study), which means that long vowels are longer by nearly 22% and short vowels are shorter by 25% in the current study as compared to the long and short vowels in (Mitleb, 1984a). The durational ratio we obtained above is relatively similar to the ratio we can calculate from (Tsukada, 2011b), which would be 117 ms (216–99 ms), but smaller than that can be calculated from (Alghamdi, 1998) for Saudi speakers, which would be nearly 147 ms (265–118 ms). As for Japanese, we can calculate the durational difference from (Tsukada, 2011b) as 101 ms (173–72 ms), which is extremely similar to the value reported in the present experiment. Our values for both short and long Japanese vowels are notably larger than those reported in (Tsukada, 2011b), yet the durational ratio is on the edge of being identical. In fact, regardless of the methodological differences that could have led to this discrepancy in values between the current study and those studies, our findings indicate that the durational difference could be an unreliable measure of vowel duration patterns, an observation which deserves its own future study.

Second, although the overall patterns of durations in both languages appear to be consistent with the patterns documented in similar studies, durational ratio is not. Specifically, short vowels consistently exhibit smaller duration values than long vowels and Japanese long vowels are generally longer than Arabic vowels. However, Japanese long vowels tend to be as twice as their short counterparts, while Arabic long vowels tend to have more than double the duration of their short counterparts. This particular aspect of the findings clearly contrasts with previous findings reporting the reverse, either based on their own data or on data borrowed from other studies, e.g. (Hirata, 2004; Tsukada, 2012a), in which durational ratio is reported as around 0.50 for Arabic and around 0.40 for Japanese, with different variations, of course. The current durational ratio is roughly 0.39 for Arabic and 0.50 for Japanese, a discrepancy that might be attributed to a major difference in the methodology used in the current study in comparison to previous studies. Some partial support comes from previous studies that share methodological facets. For example, Kalaldeh (2018) used both monosyllabic and polysyllabic MSA words for her stimuli and reported, for some vowels such as /u-uː/, durations that show a short-long durational ratio that is as low as 0.33. Similarly, Kotby *et al.* (2011) measured vowel durations of Cairene monosyllabic and polysyllabic words commonly used in MSA and reported measures that result in disparate durational ratios, some of which are as small as 0.32. For instance, they used CVC versus CV:C words for the vowel /i-iː/ and reported 133 ms for the short version and 242 ms for the long counterpart, which produces a durational ratio of roughly 0.55. However, for the /u-uː/ contrast, they used CV:CV for the long version and CVCVCVC for the short version with the second vowel being the target in both, and reported 265 ms and 86 ms, respectively. These two values will yield a durational ratio that is as low as 0.32. The durational ratio in Japanese has been reported in some studies with values that were approximate to those in Arabic. For example, Tsukada (2013) used monosyllabic Japanese words for her perception study stimuli and reported a mean of 252 ms for long vowels and a mean of 120 ms for short vowels to yield a durational ratio of 0.48. In the same studies, the durational ratio for the Arabic monosyllabic words used for the stimuli can be calculated from the short and long durations (93 ms and 209 ms, respectively) as 0.45, which is not that distant from the calculated ratio for Japanese stimuli. The Japanese durational ratio is larger than the Arabic durational ratio in her study, albeit with a small difference, which matches the pattern found in the current study. Nevertheless, in a previous study by Tsukada (2012a) in which Japanese disyllabic words and Arabic monosyllabic words were used, the durational ratios for the two languages were documented as 0.42 and 0.45, respectively. All this draws our attention to the potential impact of vowel position and syllable structure on temporal acoustics, including vowel duration, durational ratio, and durational difference.

Third, among the three types of vowel quality (be they short or long), the low vowel /a/ tends to be the longest while the high front vowel /i/ tends to be the shortest, in line with many previous findings. For instance, Ammar *et al.* (2014) present a graph showing that the vowel /i-iː/ appears to have the smallest duration value for Tunisian (≈ 40 ms for short and 80 ms for long) and for Moroccan (≈ 50 ms for short and 100 ms for long), compared to the vowel /a-aː/, which clearly appears to have a larger duration value (than the front vowel) for Tunisian (≈ 60 ms for short and 100 ms for long) and for Moroccan (≈ 70 ms for short and 120 for long). The vowel /u-uː/ appears quite similar to the vowel /a-aː/, and inspection of the visual illustration cannot allow us to determine if there is a difference between the two vowels. Other findings such as those from (Alghamdi, 1998) for Saudi speakers, (Mitleb, 1984a) for Jordanian speakers, (Ahmed, 2008) for Libyan speakers, (Saadah, 2011) for Palestinian speakers, (Amir *et al.*, 2014) for Colloquial Arabic in Israel, and (Amir *et al.*, 2012) for Hebrew have shown a similar pattern. This is a phonetic universal known as "intrinsic vowel duration", which states that higher vowels tend to be longer than lower vowels and has been studied and explained in different languages, e.g. (Maddieson *et al.*, 1996).

Thus, our results from both experiments provide a collective answer to the two research questions posed in this study, which can be briefly stated as follows. Medial vowels of polysyllabic words are durationally distinct in both languages, which aligns with reports from previous studies that focused on word-peripheral vowels or used monosyllabic words for their stimuli. This finding shows that medial position does not introduce any changes to the phonemic status of short versus long vowels in either language. However, the detailed temporal acoustic values (i.e. measurements of duration, durational difference, and durational ratio) of medial vowels exhibit patterns that are (at least partially) dissimilar to those in previous studies. We interpret this finding as evidence that results from non medial vowels (e.g. vowels in CVC monosyllabic words or peripheral vowels in polysyllabic words) may have been influenced by factors such as stress or even hyperarticulation and syllable structure (including coda geminacy), as will be briefly discussed below. These potential explanatory factors were the focus of the current study.

It has long been documented that, although stress is not phonemic in Arabic (Abdo 1969; Brame, 1971), Arabic per se is classified as a stress-timed language (Abercrombie, 1967; Roach, 1982), whereas Japanese is categorized as a mora-timed language (Dauer, 1983). Most stress studies have addressed dialectal Arabic rather than MSA, but those studies focusing on MSA, e.g. (Inaba, 1998) show that Arabic can have a light (e.g. CV), heavy (e.g. CVC), or superheavy (e.g. CVCC or CV:C) syllable, and that stress assignment is dependent on the type and number of syllables. The rules that govern stress in MSA are extremely complex, especially because MSA is sometimes influenced by the speaker's dialectal background, but for illustrative purposes, consider the following stimuli items from both previous studies and the current study. In several studies by Tsukada, e.g. (Tsukada, 2011b; 2013), words such as /ruħ/ "go" and /summ/ "poison" were used to examine the temporal acoustics of short vowels. The former contains a heavy syllable (CVC), and the latter contains a superheavy syllable (CVCC), whereas their long vowel counterparts /ruːħ/ "soul/spirit" and /suːm/ "negotiate the price" only contain a superheavy (CVːC) syllable. Some other superheavy syllable items such as /daːm/ "remained" and /ʃaːbb/ "young man" differ in the coda consonant in terms of gemination, another issue that will be visited shortly. Stress falls on the ultimate syllable for monosyllabic words, on the penultimate syllable for disyllabic words, and on the antepenultimate syllable for polysyllabic words if the penultimate syllable is light, see (Halpern, 2009, for stress rules in MSA). These rules mean that all words in (Tsukada, 2011b) and other studies that used the same or similar stimuli were stressed. In contrast, words with disyllabic structure such as CVCV versus polysyllabic structure such as CVCVCVC as in Ammar *et al.* (2014) and Kotby *et al.* (2011) will have asymmetric stress assignments. Some studies, e.g. (Amir *et al.*, 2014; Kalaldeh, 2018), have emphasized that they exclusively measured stressed syllables even though their stimuli included a combination of monosyllabic, disyllabic, and polysyllabic words. Importantly, the CVCVCV Arabic short vowel items (e.g. /nabata/ "grew up") in the current study stress the antepenultimate (but not the penultimate) syllable which does not contain the target vowel here. Vowels occurring in stressed syllables are longer than those occurring in unstressed syllables in Arabic, on average, by 25%, e.g. (De Jong, Zawaydeh, 2002).

Long vowels appearing in unstressed syllables undergo another phonological process in Arabic, neutralization, in which long vowels are completely neutralized or at least uttered as half-long vowels (Halpern, 2009). For example, a word such as /maʃaːhiːr/ "celebrities" will retain the full long vowel in the final syllable because it is stressed but will likely neutralize the vowel in the medial position. However, this type of syllable structure was deliberately avoided in the construction of the current stimuli because its use would not have allowed an appropriate distinction between short and long vowels in the medial position. Nonetheless, the target long vowels in the present study appear in stressed syllables as they normally do, which may account for the new pattern in the durational ratio, in which Arabic long vowels are more than twice as long. Japanese, in contrast, utilizes moras and feet (corresponding to syllables and to higher metrical units, respectively) (Inaba, 1998), and words can be either accented or unaccented (Cutler, Otake, 1999; Hirata, 2004). Accented words have one mora that carries the accent and is marked with H, while unaccented moras are marked with L. Bimoraic CVCV words such as those in (Tsukada, 2011b) and several other experiments follow the pattern HL, which means that the first mora is accented. Most of the items in the current study are three-mora words, which means that, for the accented words, the second mora bearing the medial vowel is unaccented, HLL. The durational ratio obtained in Experiment 2 could be related to the difference in the number of moras and accent assignment between the present work and previous studies. Overall, vowel position is critical for temporal acoustics, whether we compare short and long vowel durations (as well as durational differences and durational ratio) within- or cross-language.

One remaining factor is geminacy. There is a large body of research on the interplay between the duration of the final geminate and that of the preceding vowel, e.g. (Aldubai, 2015; Ferrat, Guerti, 2017; Hassan, 2002). There is also a debate on whether the word-final singleton versus geminate contrast is preserved in Arabic. For instance, Helpern (2009) has claimed that word-final geminates are often neutralized, which may be the case with some (especially dialectal) Arabic variations, but Frej (2021) has provided empirical evidence that final gemination is maintained both articulatorily and acoustically by MSA speakers with Moroccan and Lebanese backgrounds. He also found that Moroccan and Lebanese speakers tend to shorten pregeminate vowels, but this result was not robust. Notwithstanding, an ideal study should consider geminacy as a factor in its design. Geminacy frequently occurs word-finally in Arabic and in monosyllabic words in particular, but unlike our stimuli, many previous studies have mixed words with final singletons and others with final geminates. Such an approach is probably one of the factors that yield a difference in the temporal acoustics of medial vowels in this study and non-medial vowels in previous studies.

5. Conclusion

This paper investigates whether experimental design related facets such as vowel position syllable structure (including stress and geminacy) will affect, or have affected in previous studies, measures of temporal acoustics (including vowel duration, durational difference, and durational ratio). As way to resolve these potential issues, the current study measured vowel temporal acoustics in the medial position of polysyllabic words in two languages that have been frequently compared in previous studies: Arabic and Japanese. In general, the overall findings in the present study are mainly compatible with patterns found in previous studies using monosyllabic structure items or mixed monosyllabic and polysyllabic structure words. Short vowels are clearly longer than their long counterparts in both languages. However, the actual durations of both short and long medial vowels exhibit divergent values from those reported in previous studies. The durational ratio shows a new output that makes the relationship between short and long vowels in Arabic and Japanese clearly different from that established in relevant studies. That is, the Arabic long vowels in medial positions of polysyllabic words are no longer as twice as their short counterparts, nor are the Japanese long vowels more than twice as long as their short counterparts in the medial position of polysyllabic words. Thus, one can recommend that both vowel position and item structure (including syllable stress and geminacy) be taken into consideration when constructing stimuli to investigate vowel duration; otherwise, durations of short-long vowels in a particular position may not represent well the duration of the vowels in other positions. One additional outcome of this study is the observation that, although new patterns observed in the current findings can be attributed to the factors discussed above, durational difference does not seem to be a good metric for describing vowel duration. Therefore, future research to examine durational difference as a questionable duration metric is recommended. Finally, a comparison between the temporal acoustics of a variety of Arabic and that of another variety or even another language such as Japanese is inherently complex and involves numerous factors that must be carefully considered, such as vowel position, number of syllables or moras, stress versus accent assignment, neutralization, and geminacy.

Acknowledgments

The author would like to thank the Deanship of Scientific Research at King Saud University for funding and supporting this research.

References

1. Abdo D.A. (1969), *Stress and Arabic phonology*, Ph.D. Thesis, Language and Literature, Linguistics, University of Illinois at Urbana-Champaign, https://www.proquest.com/openview/bbc80e69d2dd5f845541051e522bde90/1?pq-origsite=gscholar&cbl=18750&diss=y.
2. Abercrombie D. (1967), *Elements of General Phonetics*, Aldine Publishing Company, Chicago.
3. Ahmed A.A.M. (2008), *Production and perception of Libyan Arabic vowels*, Ph.D. Thesis, School of Education, Communication, and Language Sciences, Newcastle University, http://hdl.handle.net/10443/846.
4. Al-Ani S.H. (1970), *Arabic Phonology: An Accoustical and Physiological Investigation*, Mouton Publisher.
5. Aldholmi Y., Alotaibi S., Alrouqi M. (2021), Rating nonnativeness in L1-Japanese L2-Arabic Speakers' Vowels, [in:] *Proceedings of the 12th International Conference of Experimental Linguistics (ExLing 2021)*, pp. 9–12, doi: 10.36505/ExLing-2021/12/0003/000476.
6. Aldubai N.A. (2015), The impact of geminates on the duration of the preceding and following vowels in Ta'zi dialect, *Arab World English Journal (AWEJ)*, **6**(1): 335–358, doi: 10.2139/ssrn.2834455.
7. Alghamdi M.M. (1998), A spectrographic analysis of Arabic vowels: A cross-dialect study, *Journal of King Saud University – Journal of Arts*, **10**(1): 3–24, https://arts.ksu.edu.sa/sites/arts.ksu.edu.sa/files/imce_images/v10m190r1962.pdf.
8. Almbark R., Hellmuth S. (2015), Acoustic analysis of the Syrian vowel system, [in:] *The 18th International Congress of Phonetic SciencesICPhS*, http://eprints.hud.ac.uk/28138/.
9. Almisreb A.A., Abidin A.F., Tahir N.M. (2016), An acoustic investigation of Arabic vowels pronounced by Malay speakers, *Journal of King Saud University – Computer and Information Sciences*, **28**(2): 148–156, doi: 10.1016/j.jksuci.2015.08.003.
10. Al-Tamimi J., Barkat-Defradas M. (2003), Inter-dialectal and inter-individual variability in production and perception: a preliminary study in Jordanian and Moroccan Arabic, [in:] *Proceedings Association Internationale de Dialectologie Arabe (5th AIDA)*, pp. 171–186, http://www.ddl.ish-lyon.cnrs.fr/fulltext/Al-Tamimi/Al-Tamimi_2002_AIDA.pdf.
11. Amir N., Amir O., Rosenhouse J. (2014), Colloquial Arabic vowels in Israel: A comparative acoustic study of two dialects, *The Journal of the Acoustical Society of America*, **136**(4): 1895–1907, doi: 10.1121/1.4894725.
12. Amir N., Tzenker O., Amir O., Rosenhouse J. (2012), Quantifying vowel characteristics in Hebrew and Arabic, [in:] *Afeka-AVIOS Speech Processing Conference*, pp. 37–43, https://www.isca-speech.org/archive_v0/avios_12/papers/avio_037.pdf.
13. Ammar Z., Fougeron C., Ridouane R. (2014), In search of dialectal traces in Standard Arabic: production of vowels and interdental fricatives by Tunisian and Moroccan speakers [in French: A la recherche des traces dialectales dans l'arabe standard: production des voyelles et des fricatives interdentales par des locuteurs tunisiens et marocains], [in:] *30èmes Journées d'Etudes sur la Parole (JEP 2014)*, https://halshs.archives-ouvertes.fr/halshs-01401827.
14. Boersma P., Weenink D. (2022), *Praat: doing phonetics by computer*, Computer program, Version 6.2.09, http://www.praat.org/ (access: 15.01.2022).
15. Brame M.K. (1971), *Stress in Arabic and generative phonology*, **7**(4): 556–591, https://www.jstor.org/stable/25000563.
16. Cantineau J. (1956), The phonemic system of Damascus Arabic, *Word*, **12**(1): 116–124, doi: 10.1080/00437956.1956.11659595.
17. Cowan W. (1970), The vowels of Egyptian Arabic, *Word*, **26**(1): 94–100, doi: 10.1080/00437956.1970.11435584.

18. Cutler A., Otake T. (1999), Pitch accent in spoken-word recognition in Japanese, *The Journal of the Acoustical Society of America*, **105**(3): 1877–1888, doi: 10.1121/1.426724.

19. Dauer R.M. (1983), Stress-timing and syllable-timing reanalyzed, *Journal of Phonetics*, **11**(1): 51–62, doi: 10.1016/S0095-4470(19)30776-4.

20. De Jong K., Zawaydeh B. (2002), Comparing stress, lexical focus, and segmental focus: Patterns of variation in Arabic vowel duration, *Journal of Phonetics*, **30**(1): 53–75, doi: 10.1006/jpho.2001.0151.

21. Ferguson C.A. (1957), Two problems in Arabic phonology, *Word*, **13**(3): 460–478, doi: 10.1080/00437956.1957.11659647.

22. Ferrat K., Guerti M. (2017), An experimental study of the gemination in Arabic language, *Archives of Acoustics*, **42**(4): 571–578, doi: 10.1515/aoa-2017-0061.

23. Flege J.E., Port R. (1981), Cross-language phonetic interference: Arabic to English, *Language and Speech*, **24**(2): 125–146, doi: 10.1515/aoa-2017-0061.

24. Frej M.Y. (2021), *The production and perception of peripheral geminate/singleton coronal stop contrasts in Arabic*, Ph.D. Thesis, The MARCS Institute for Brain, Behavior and Development, Western Sydney University, Australia, http://hdl.handle.net/1959.7/uws:62306.

25. Halpern J. (2009), Word stress and vowel neutralization in modern standard Arabic, [in:] *Proceedings of 2nd International Conference on Arabic Language Resources and Tools*, pp. 1–7, http://www.elda.org/medar-conference/.

26. Harris Z.S. (1942), The phonemes of Moroccan Arabic, *Journal of the American Oriental Society*, **62**(4): 309–318, doi: 10.2307/594035.

27. Hassan Z.M. (1981), *An experimental study of vowel duration in Iraqi spoken Arabic*, Ph.D. Thesis, Department of Linguistics and Phonetics, University of Leeds, https://etheses.whiterose.ac.uk/2345/.

28. Hassan Z.M. (2002), Gemination in Swedish and Arabic with a particular reference to the preceding vowel duration: an instrumental and comparative approach, [in:] *Proceedings of Fonetik*, **44**(1): 81–84, https://www.speech.kth.se/prod/publications/files/qpsr/2002/2002_44_1_081-084.pdf.

29. Hirata Y. (2004), Effects of speaking rate on the vowel length distinction in Japanese, *Journal of Phonetics*, **32**(4): 565–589, doi: 10.1016/j.wocn.2004.02.004.

30. Hong S.A., Sarmah P. (2009), Korean perception of Arabic phonemes, *Current Issues in Linguistic Interfaces*, **2**: 375–386.

31. Inaba S. (1998), Moras, syllables, and feet in Japanese, [in:] *Proceedings of the 12th Pacific Asia Conference on Language, Information and Computation*, pp. 106–117, https://aclanthology.org/Y98-1000.

32. Kalaldeh R. (2018), Acoustic analysis of Modern Standard Arabic vowels by Jordanian speakers, *International Journal of Arabic-English Studies*, **18**(1): 23–48, http://www.ijaes.net/article/FullText/2?volume=18&issue=1.

33. Kawahara S. (2015), The phonetics of sokuon, or geminate obstruents, [in:] *Handbook of Japanese Phonetics and Phonology*, pp. 43–78, De Gruyter Mouton, doi: 10.1515/9781614511984.43.

34. Klatt D.H. (1976), Linguistic uses of segmental duration in English: Acoustic and perceptual evidence, *The Journal of the Acoustical Society of America*, **59**(5): 1208–1221, doi: 10.1121/1.380986.

35. Kotby M.N. *et al.* (2011), The Arabic vowels: Features and possible clinical application in communication disorders, *Folia Phoniatrica et Logopaedica*, **63**(4): 171–177, doi: 10.1159/000316323.

36. Lababidi Z., Park H. (2016), L1-English tense-lax vowel system influence on L2-Arabic short and long vowel learning, [in]: *Perspectives on Arabic Linguistics XXVIII: Papers from the Annual Symposium on Arabic Linguistics*, Gainesville, Florida, pp. 63–88, doi: 10.1075/sal.4.03lab.

37. Maddieson I., Hardcastle W.J., Laver J. (1996), Phonetic universals, [in:] *UCLA Working Papers in Phonetics*, pp. 160–178, Los Angeles.

38. Mitleb F. (1984a), Vowel length contrast in Arabic and English: A spectrographic test, *Journal of Phonetics*, **12**(3): 229–235, doi: 10.1016/S0095-4470(19)30879-4.

39. Mitleb F.M. (1984b), Voicing effect on vowel duration is not an absolute universal, *Journal of Phonetics*, **12**(1): 23-27, doi: 10.1016/S0095-4470(19)30847-2.

40. Mori Y., Erickson D. (2008), Effects of accentual fall on phrase-final vowel duration in Japanese, *Phonetica*, **65**(3): 148–172, doi: 10.1159/000144079.

41. Roach P. (1982), On the distinction between 'stress-timed' and 'syllable-timed' languages, *Linguistic controversies*, https://www.semanticscholar.org/paper/On-the-distinction-between-%27stress-timed%27-and-Roach/f7dd8652431bff1a757ead50b0e49921a54444e9.

42. Saadah E. (2011), *The production of Arabic vowels by English L2 learners and heritage speakers of Arabic*, Ph.D. Thesis, Department of Linguistics, University of Illinois at Urbana-Champaign, http://hdl.handle.net/2142/24104.

43. Sagisaka Y. (1984), Phoneme duration control for speech synthesis by rule, *IEICE Transactions Fundamentals (Japanese Edition), A*, **67**(7): 629–636, https://cir.nii.ac.jp/crid/1573105974984442752.

44. Smith B.L. (1987), Effects of bite block speech on intrinsic segment duration, *Phonetica*, **44**(2): 65-75, doi: 10.1159/000261781.

45. Takeda K., Sagisaka Y., Kuwabara H. (1989), On sentence-level factors governing segmental duration in Japanese, *The Journal of the Acoustical Society of America*, **86**(6): 2081–2087, doi: 10.1121/1.398467.

46. Tsukada K. (2009), An acoustic comparison of vowel length contrasts in Arabic, Japanese and Thai: Durational and spectral data, *International Journal on Asian Language Processing*, **19**(4): 127–138, https://colips.org/journals/volume19/19_4_-1-Kimiko-Tsukada.pdf.

47. Tsukada K. (2010), Vowel Length Categorization in Arabic and Japanese: Comparison of Native Japanese and Non-native Learners' Perception, [in:] *13th Australasian International Conference on Speech Science and Technology*, pp. 126–129, https://assta.org/proceedings/sst/SST-10/SST2010/PDF/AUTHOR/ST100010.PDF.

48. Tsukada K. (2011a), Effect of multi-lingualism on the perception of short and long vowels in Arabic and Japanese, [in:] *Proceedings of the 17th International Congress of Phonetic Sciences ICPhS*, pp. 2034–2037, https://researchers.mq.edu.au/en/publications/effect-of-multi-lingualism-on-perception-of-short-and-long-vowels.

49. Tsukada K. (2011b), The perception of Arabic and Japanese short and long vowels by native speakers of Arabic, Japanese, and Persian, *The Journal of the Acoustical Society of America*, **129**(2): 989–998, doi: 10.1121/1.3531801.

50. Tsukada K. (2012a), Comparison of native versus nonnative perception of vowel length contrasts in Arabic and Japanese, *Applied Psycholinguistics*, **33**(3): 501–516, doi: 10.1017/S0142716411000452.

51. Tsukada K. (2012b), Non-native Japanese listeners' perception of vowel length contrasts in Japanese and Modern Standard Arabic (MSA), *Second Language Research*, **28**(2): 151–168, doi: 10.1177/0267658311435870.

52. Tsukada K. (2013), Vowel length categorization in Arabic and Japanese: Comparison of native and non-native Japanese perception, *Speech, Language and Hearing*, **16**(4): 187–196, doi: 10.1179/2050572813Y.0000000012.

53. Zaltz Y., Segal O. (2022), The perception of Arabic vowel duration by L1 Hebrew speakers: Can a short training remold the effect of the native phonological system?, *Studies in Second Language Acquisition*, **44**(1): 143–163, doi: 10.1017/S0272263120000728.