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A Perceptual Study of CV Syllables in both Spoken and Whistled Speech: a Tashlhiyt Berber Perspective

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Abstract

The present study compares the perceptual categorization of four CV syllables /ta, da, ka, ga/ in two different speech registers - modal speech and whistled speech - of Tashlhiyt Berber used in the Moroccan High Atlas. Whistled speech in a non-tonal language such as Tashlhiyt is a special speech register used for long distance dialogues that consists of the natural production of vocalic and consonantal qualities in a simple modulated whistled signal. The technique of whistling imposes various restrictions on speech articulation, which result in a simplification of the phonetics of spoken speech into a 'whistled formant'. Here, we describe this simplification for Tashlhiyt syllables /ta, da, ka, ga/ and use them as stimuli in a behavioral experiment. We analyze and compare the perceptual categorization obtained from native Tashlhiyt listeners (trained since childhood in whistled speech) for both speech registers on these 4 syllable types. Results show that whistled stimuli were fairly well identified (~42%) above chance (25%), though less well than spoken ones (~84%). The detailed analysis of confusions between CVs enabled us to understand better how whistled consonants are perceived, highlighting the phonological contrasts that are best perceived and retained from spoken to whistled speech in this language.

Index Terms: speech recognition, Tashlhiyt, whistled speech, dichotic paradigm, homophones, lateralization.

1. Introduction

Whistled speech is an ancient traditional and natural language practice that consists in a phonetic transformation of the spoken signal into a simple melodic line made up of frequency and amplitude whistled modulations. It encodes key salient phonetic cues of the acoustic and articulatory features of languages. It was recently found in the Tashlhiyt language among shepherds of several villages in the High Atlas of Morocco [1, 2]. These Tashlhiyt native speakers learn since childhood to copy any sentence of their language into a simpler whistled signal. Strikingly, in non-tonal languages such as Tashlhiyt but also Greek, Turkish or Spanish, the whistled modulated line is sufficient to guarantee high levels of sentence intelligibility by trained speakers even if it is not directly intelligible to naïve listeners [3]. Yet, it is easily learned by speakers of the language, as attested by the current efforts made for the revitalization of whistled Spanish in the Canary Islands [4, 5]. In former studies, we examined how some phonological properties of Tashlhiyt are rendered in whistled speech, focusing on syllable structure and how it relates to the vocalic and consonantal system of the language [1, 6]. We found that whistlers approximate the vocal tract articulation used in spoken form. This provokes a whistled adaptation of vowel and consonant qualities carried by the timbre of the voice as was observed for other non-tonal languages (resembling more directly to formant 2 and/or 3 patterns [1,7]). Full Tashlhiyt vowels /a, i, u/ are whistled in specific intervals of frequencies. Typically, in Tashlhiyt /i/ is whistled with the highest pitch, /a/ is lower, and /u/ even lower [7]. On another hand, consonants are represented by continuous or interrupted modulations of these vocalic whistles. They also depend on the consonantal articulatory loci: for example, when associated with /a/, coronals /t, d/ modulate towards high frequencies; whereas velars /k, g/ modulate towards low frequencies [1, 7] (Fig.1).

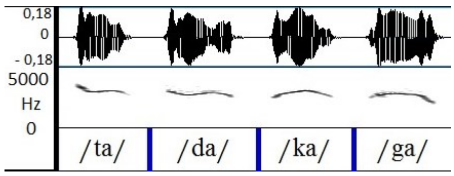

Figure 1. *One example of whistled stimuli per CV type*

The present study compares the perceptual categorization of the four CV syllables /ta, da, ka, ga/ by fluent native speakers in whistled and spoken Tashlhiyt. We replicated the protocol of a recently published experiment, which was the first to use a behavioral technique based on a dichotic listening paradigm in both whistled and spoken speech (in Turkish) [8]. Here, we tested a non-related language, and fewer CV types (the study on Turkish tested /ta, da, ka, ga, pa, ba/ initial syllables, but given that Tashlhiyt does not have the phoneme /p/ we didn't include the voiced/unvoiced contrast /pa/-/ba/). Moreover, the original test on Turkish included two conditions with participants simultaneously hearing via headphones either same (homophonic condition) or different CV types (dichotic condition) on left and right ears. In the present study, we limited our analysis to the homophonic condition, evaluating the confusion rates between different CV types (ex: /ta/ taken for /ka/, etc…) after deriving two confusion matrices from the answers (spoken and whistled). We hypothesized to find high rates of confusion between CV types for whistled speech, but not for spoken modal speech. Indeed, all studies having tested whistled speech have found high confusion rates in perception due to the whistled acoustic reduction (see [3, 9] for reviews). We also expected higher confusion rates between /da/ and /ta/; but also /ga/ and /ka/ in whistling (similar frequency shapes (Fig.1) and absence of voicing distinction in whistles). Such confusions are important to observe in details because they may influence results in the dichotic condition. The study of which we replicate the protocol didn't provide any analysis of

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homophone confusion, even if the rates of correct answers they found were relatively low for whistling [8]. This is questioning the validity of the very strong claims drawn from their results on the dichotic condition [8]. For example, they argued that the traditionally reported left hemispheric lateralization of speech was challenged by whistled speech perception. However, such a conclusion might just be wrong as its validation depends of the analysis of the confusion matrix of homophones. Indeed, the question remains whether their observed absence of an apparent lateralization in whistled speech was due to a purely acoustic reason (a simple whistled melody to encode speech), or to a phonetical-phonologic reason/bias (whistled speech production is less precise than the spoken one and therefore results in more confusions between CV syllable, or a combination of the two.

As a consequence, our study not only provides original experimental fieldwork results on a rare practice recently discovered in the Moroccan Atlas, but also proposes a replicable methodology to prepare the stimuli and to analyze the confusion matrix between played and answered CV syllables in whistled speech. This may be useful to improve original recent studies addressing important questions in language sciences and brain studies.

2. Methods

2.1. Participants

The 9 participants were 25 to 42 year-old Tashlhiyt native speakers and whistlers. They were all voluntary villagers of the Moroccan High Atlas, practicing whistled speech since childhood. None of them reported hearing impairment. All reported being right handed. The present study was conducted in accordance with the Declaration of Helsinki.

2.2. Stimuli

The sound extracts used as stimuli were selected in a corpus of Berber Tashlhiyt whistled and spoken CV syllables recorded in 2015 in the High Atlas (Morocco) by the first and the last authors. The four tested CV types were /ta/, /da/, /ka/, /ga/. In Berber, just as in Spanish and Turkish (two languages for which whistled speech has been also studied perceptually), consonants /t/ and /d/ are dental in initial position and consonants /k, g/ are not palatalized in front of /a/. In the whistled speech realization of these consonants, a first important particularity is the absence of voiced sounds that characterize modal voiced consonants, limiting the possibility to differentiate /d/ from /t/ or /k/ from /g/. One consequence is that there is a silence in the place of prevoicing in whistling. In order to harmonize whistled and spoken conditions in this respect , we decided not to include the prevoicing of voiced consonants in spoken modal stimuli (note that this also guaranteed that we wouldn't create any bias in favor of voiced consonants in future developments of the study such as dichotic condition with spoken stimuli).

The experimental material consisted of 16 CV spoken and 16 CV whistled sounds (4 /ta/, 4 /da/, 4 /ka/ and 4 /ga/ in each speech register). They were extracted from a large corpus of CV repetitions produced by a same speaker/whistler, known for his very high proficiency in whistled speech. He was asked to alternatively repeat and contrast clearly and slowly the pairs of CV syllables /ta/-/da/ (repeating several times /da/ followed by /ta/), and next the /da/-/ta/, then /ka/-/ga/, and then /ga/-/ka/. In order to retain the same prosody on each syllable chosen as stimulus for the test, we systematically selected audio samples that were uttered first in a pair. With such an elicitation procedure, syllables produced in pairs were naturally well contrasted. This is particularly important because whistled /ta/ and /da/, on one hand, and /ka/ and /ga/, on the other hand, are less easily contrasted than in spoken modal speech because of the absence of voicing. All recordings were made in a single session in controlled conditions (same whistling technique during the entire session, constant distance from the recorder (ZoomH4N at 1 meter), and quiet background noise between 30 and 40 dB(A)). In whistled speech, vowel nuclei are typically whistled as rather steady in frequency and are modulated at their extremity by the consonant articulation(s). For whistled CVs, they included the consonant modulations before the vowel which is clearly different between coronals and velars, while /d, g/ generally show a less sharp attack in both amplitude and frequency of their /t, k/ counterparts (see [7] and Fig.1.)

2.3. Design and procedure

The two experiments (spoken and whistled) used the same design that included two phases: training and test. The training was composed of 4 sounds, presented in a fixed order (1 of each CV type, composed of homophones presented simultaneously in the left and right ear). The training ensured that the task was well understood. The test consisted in the presentation of 16 sounds, each composed of two different homophones presented simultaneously in the right and left ear. The 16 sounds were randomly presented (4 of each CV type /ta/, /da/, /ka/, /ga/ selected randomly in the pool of combinations not yet presented).and different from the ones of the training. The participant listened to each sound played one by one in the headphones and immediately afterward pronounced loudly to the experimenter the CV type that he estimated was closest to the one heard ("ta", "da", "ka", or "ga"). One experimenter fluent in Tashlhiyt clicked on the answer that was spoken loudly by the participant (as most of the participants were illiterate). Clicking on the answer started the next trial. The test followed directly after the training. Only one listening was possible per stimulus, no feedback (training and test). Overall, the experiment was maintained short for the experiment to remain ludic and pleasant to the participants who were all shepherd or ex shepherds of the region, and therefore not acquainted to this kind of psycholinguistic test. The time taken to answer was not recorded, but only the answers themselves. The test and its interface were programmed in Matlab and presented on a PC computer with high quality soundcard in a quiet room using high-quality Sennheiser headphones (HD 449). The volume was comfortable, around 70 dB(A). The stimuli had been previously normalized on the max of intensity of each sound extract. The two homophones presented dichotically were aligned temporally on the beginning of each sound, more precisely on the starting point of the attack of each sound: left and right sound extracts were presented in complete synchronization. The same point of synchronization was used for spoken and whistled speech, as prevoicing was removed from /da/ and /ga/ spoken stimuli.

2.4. Statistical analyzes

Confusion matrices of the answers ("ta", "da", "ka", "ga") as a function of the played CVs (/ta/, /da/, /ka/, /ga/) were derived from the participants' answers (see Table 1 for participants listening to modal spoken speech and Table 2 for participants listening to whistled speech). Four different types of analyzes were performed on these data. First, an evaluation of the agreement of the answers with the played categories according to Cohen's Kappa statistics which give a quantitative measure of the magnitude of such an agreement while being adjusted for agreement because of random chance alone [10,11]. Next, we statistically analyzed the variations of the qualitative 'answer' variable (binary: either right or wrong; called DETECTION in the models) as a function of several explanatory variables, including their interactions. One model was built to compare answers on spoken vs. whistled stimuli. Another model was built to analyze in details CV categorization in whistled stimuli alone. Given that a participant was solicited 4 times for each, we introduced the variable SUBJECT as a random effect in the models. Given these conditions, we chose to use logistic regression with random effect, using the function *glmer* of the package *lme4* of R [12]. In order to test the effect of the parameters, we use the likelihood ratio test (*anova* function of R). To evaluate the performance of the models we used the AUC (Area Under Curve) of the ROC curve [13] (package *AUC* of R). The multiple comparisons were done with Hothorn & al.'s method [14] using the function *glht* (package *multcomp* of R) after building appropriate matrices of contrasts (function *lsmeans* from package *lsmeans*). This ensures that the overall type I error associated with the simultaneous decisions do not exceed the pre-specified significance level (here 0.05, as usual) by adjusting p-values [15]. More details on each model are provided in the next section. Finally, an additional exploration of the whistled matrix was done to analyze more specifically confusions found in participants' incorrect answers. For this purpose, we performed two statistical tests exploring the CV type effects on such incorrect answers. One was an accordance test to the chance proportion. And the second was a comparison test of proportions between correct and incorrect answers.

3. Results

3.1. Confusion matrices and correct answers

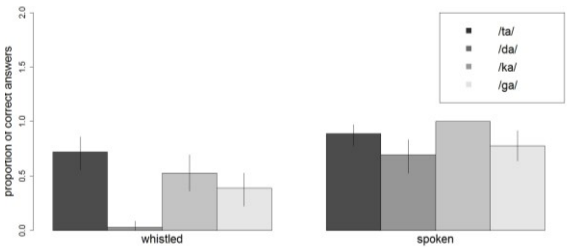

Figure 2. *Proportion of correct answers (with indicated bootstraps of confidence interval) as a function of condition (whistled or spoken) and of CV types (/ta/, /da/, /ka/, /ga/)*

3.1.1. Modal speech: categorization of spoken CVs

Table 1: *Confusion matrix for the answers of 9 native speakers categorizing spoken CVs (number of answers). Values in italics correspond to correct answers.*

	Answered spoken CVs				
		« ta »	« da »	« ka »	« ga »
Played Spoken CVs	/ta/	*32*	0	4	0
	/da/	6	*25*	2	3
	/ka/	0	0	*36*	0
	/ga/	0	0	8	*28*

Table 1 presents the confusion matrix for modal speech. The mean level of success corresponding to correct answers was very high: 121 out of 144 (84%). /da/ gave the worst levels (69,4%), while /ga/ reached 77.7%, /ta/ 88.9% and /ka/ 100%. The most frequent confusions were /ga/ mistaken for "ka" (22.2% of played /ga/), /da/ mistaken for "ta" (16.7% of the cases), and /ta/ mistaken for "ka" (11.1% of played /ta/). The agreement of the answers with the CV categories was different from chance and not accidental, as it was 'good' almost 'substantial' according to Cohen's kappa statistics (k = 0.787).

3.1.2. Whistled speech: categorization of whistled CVs

In spite of the difficulty of the whistled speech task, all participants succeeded relatively well as they reached between 31.25% and 50% of correct answers (chance is at 0.25, because there are four possible answers), which confirmed their proficiency. Table 2 presents the confusion matrix of the Tashlhiyt listeners for whistled speech. The agreement of the answers with the CV categories was not accidental (Cohen's kappa k = 0.222, 'fair' agreement). The mean level of success corresponding to correct answers was 60 out of 144 (41.7%). However, /da/ gave the worst performances as it was this time almost ignored (0,03%), far below chance, while /ga/ reached 38.9% of correct categorization, and /ka/ 52,77% and /ta/ 72.1% were far better recognized (see also Fig.2). As for confusions, the most frequent ones were /da/ mistaken for "ta" (55.6% of played /da/), /ga/ mistaken for "ka" (41.7% of played /ga/), /ka/ mistaken for "ta" (30.6% of played /ka/), and /da/ mistaken for "ka" (25% of played /da/).

Table 2: *Confusion matrix for the answers of 9 native whistlers (in number of answers) categorizing whistled CVs. Values in italics correspond to correct answers.*

	Answered whistled CVs				
		« ta »	« da »	« ka »	« ga »
Played Whistled CVs	/ta/	*26*	2	6	2
	/da/	20	*1*	9	6
	/ka/	11	1	*19*	5
	/ga/	3	4	15	*14*

3.1.3. Comparison of spoken and whistled results

To find out if whistled CVs are categorized similarly or differently to spoken CVs by the trained whistlers, despite the lower rates of correct answers, we evaluated statistically the impact of the played CVs (factor PLAYED with four levels: /ta/, /da/, /ka/, /ga/), the speech register (factor SPEECHTYPE with two levels, "spoken" and "whistled") and of their interaction of second order on the binary answer variable called DETECTION with two levels, 'right' or 'wrong' (model 1).
There was a complete separation for the combination (PLAYED=/ka/, SPEECHTYPE="spoken") because it resulted in complete correct detection. As a consequence we chose to exclude the level /ka/ of the factor PLAYED (note, however, that it was clearly less well recognized in the whistled condition as it reached a score of 52,77% of correct answers). The backward selection using the likelihood ratio test lead us not to keep the random effect SUBJECT-PLAYED (chisq(5)=7.7, p=0.17), which means that, if the intersubject variability exists, it doesn't change when the participants pass from one level to another of the factor PLAYED. It also lead us to keep the fixed effect of the interaction between the factors PLAYED and SPEECHTYPE (chisq(2)=10.24, p=0.005) meaning that the impact of the factor PLAYED is different according to the levels of the factor SPEECHTYPE. The AUC was 0.88, which is a very satisfying measure. Multiple comparisons on Table 3 show that spoken and whistled registers are significantly different for PLAYED /da/, /ga/ but not for /ta/.

Table 3: *Multiple comparisons of the scores on correct answers of each of the 3 CV types of the model 1 as a function of the speech register (significant p-values in bold).*

Hypothesis	Estimate	SD	z-value	pvalue
Whistled-Spoken|**/da/**	-4.67	1.19	-3.91	**0.00027**
Whistled-Spoken|**/ga/**	-1.91	0.64	-2.98	**0.0085**
Whistled-Spoken /ta/	-1.28	0.75	-1.69	0.24

3.1.4. Detailed analysis of whistled categorization

To understand in more details the discrimination of the whistled CVs we evaluated statistically the impact of the played CVs (factor PLAYED with four levels: /ta/, /da/, /ka/, /ga/), on the binary response variable (called DETECTION with two levels, 'right' or 'wrong') only in the case SPEECHTYPE = 'whistled' (in this case, there was no complete separation and we could include the level /ka/ of the factor PLAYED). The backward selection using the likelihood ratio test lead us to exclude the random effect SUBJECT-PLAYED (chisq(9)=6.74, p=0.66), which means that the intersubject variability was not significantly relevant when the participants passed from one CV type to another of the factor PLAYED. By contrast, we kept the fixed effect of the factor PLAYED (chisq(3)=46.01, p<0.0001) which means that there are at least two levels of this factor for which the difference is significant. The AUC was at 0.78, which is a suitable value. Finally, multiple comparisons on Table 4 show that scores on correct answers of /ta/ were significantly different from /da/ and /ga/ but not from /ka/. Scores on /da/ were statistically different from the three other CV types. Correct scores on /ka/ were significantly different from /da/ but not from /ta/ or /ga/. And finally that correct scores on /ga/ were significantly different from /ta/, /da/ but not /ka/.

Table 4: *Multiple comparisons of the scores on correct answers of each pair of CV type (significant p-values in bold).*

Hypothesis	Estimate	SD	z-value	pvalue
da – ga	-3.1034	1.0703	-2.8996	**0.0171**
da – ka	-3.6666	1.0677	-3.434	**0.003**
da – ta	-4.5109	1.0803	-4.1756	**<0.0001**
ga – ka	-0.5632	0.4778	-1.1786	0.6235
ga – ta	-1.4075	0.5053	-2.7854	**0.0246**
ka – ta	-0.8443	0.4999	-1.6889	0.3116

3.2. Analysis of whistled Confusions

Observation of the confusions revealed other interesting aspects of the results. The analysis of the whistled confusion matrix was done by performing two statistical tests exploring the CV type effects on incorrect answers. The first test aimed at detecting some significant confusions between played and answered CV types by looking at the ones that reached a probability significantly higher than the threshold of chance (here 0.25). For this, we used the *binom.test* function of the *R* software and performed twelve accordance tests to a proportion, for each cell in the confusion matrix outside the diagonal. We compared the p-value obtained at each test with the threshold corresponding to the bonferonni correction (0.05/12). The results show that for whistled speech, the sound /da/, when presented, was significantly taken for "ta" CV type (p<0.0001). We also find a tendency showing that the /ga/ sound, when presented, was taken for "ka" CV type (p= 0.0209). The second test, complementary to the first one, was intended at testing whether the incorrectly answered CV types were in the same proportions as the expected ones (correct answers). 12 comparison tests of proportions were performed on the confusion matrix, by using the function *prop.test* of the *R* software. Results showed that "ka" was clearly answered in the same proportion as "ga" when a /ga/ sound was played, thus confirming strongly the tendency found in the first test. Moreover, they show that we cannot completely reject the idea that "ta" was answered in the same proportions as "ka" when a /ka/ was played. The same goes for "ga" and "da" when the /da/ was played, but it must be discarded due to very low number of answers.

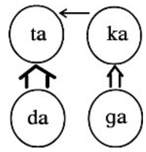

Figure 3: *Confusions in the whistled experiment (double arrows: significant confusions; simple arrow: just tendency)*

4. Discussion and Conclusions

We explored how Tashlhiyt native listeners fluent in both spoken and whistled speech categorized the spoken and whistled syllables /ta, da, ga, ka/. The present study was designed to contribute to a better understanding of the relation between whistled and spoken speech perception, particularly to propose improvements in the case of forced choice tasks applied to dichotic paradigms. We illustrated our proposal with the case study of a rarely studied language. Our stimuli were homophones presented in a dichotic paradigm, and we chose to align temporally left and right ears' sounds in the same way in whistled and spoken syllables (as prevoicing is not present in whistling, we didn't keep it for the spoken stimuli). Recognition levels for spoken speech were high. All participants also succeeded relatively well in the whistled syllable test. Overall, whistled syllables were significantly less well recognized than spoken ones for all CV types except /ta/. In order to look more closely at the whistled experiment, we performed a number of statistical tests. First, we noted that there was no significant confusion effect between different loci of articulation (coronal vs. velar), but just a slight tendency of /ka/ towards /ta/. By contrast, we found that voiced phonological categories, when whistled, are largely taken for their unvoiced counterparts (double arrows in Fig.3). This result is in line with the fact that voicing is not produced in whistling and thus not easily recoverable. However, there were different proportions of such confusion for coronals (/t, d/) vs. velars (/k, g/). The latter effect is likely to be explained by other influences on perception performances which are lexical and phonotactical. For example, /da/ is almost completely swallowed by /ta/might be well due to the fact that in Tashlhiyt the distribution of the word-initial /ta/ in the lexicon is very high while initial /da/ is extremely rare [16]. One reason is that feminine forms have the shape /ta-…-t/ (e.g. a-frux (m) 'boy', t-a-frux-t (f) 'girl') and that the use of gender is not limited to a subset of the animate nouns, it can also mark a process of derivational morphology [17]

Finally, our analysis shows that confusion matrices of homophones in a dichotic paradigm should be studied in details in the case of whistled speech because of high levels of confusion, eventually reinforced by language dependent factors. That is why this study should encourage other studies to adopt a similar approach on other languages, particularly in the perspective of analyzing, weighing and unraveling results on dichotic condition to eventually explore lateralization of whistled speech as in [8], or of other practices that imply more confusion than modal speech listened in quiet conditions.

5. References

[1] J. Meyer, B. Gautheron, and R. Ridouane, "Whistled Moroccan Tamazight: phonetics and phonology", *Proceedings of the 18th International Congress of Phonetic Sciences*, Glasgow, 2015.

[2] G. Pucheu, "Notes sur la parole sifflée en usage dans le Haut-Atlas marocain. Premières observations ", *Asinag*, 10, 51-64 2015.

[3] J. Meyer, "*Whistled Languages. A Worldwide Inquiry about Whistled Speech*", Berlin: Springer, 2015.

[4] J. Meyer, "'Whistled languages' reveal how the brain processes information".*Scientific American*, 316, pp. 61–67, 2016.

[5] J. Meyer and D. Diaz " Geolingüistica de los lenguajes silbados del mundo, con un enfoque en el español silbado ". *Géolinguistique*, 17, pp.99-124, 2018.

[6] R. Ridouane, G. Turco, and J. Meyer, "Length Contrast and Covarying Features: Whistled Speech as a Case Study". In Proceedings of the 19th Annual Conference of the International Speech Communication Association (Interspeech 2018), Hyperabad, India,.pp. 1843-1847, 2018.

[7] J. Meyer, "Phonetics, Phonology and Typology of Whistled Languages" in Meyer J. "*Whistled Languages. A Worldwide Inquiry about Whistled Speech*", Berlin: Springer, pp 105-131. 2015.

[8] O. Güntürkün, M. Güntürkün, and C. Hahn. "Whistled Turkish alters language asymmetries." *Current Biology, 25*, 16 10.1016/j.cub.2015.06.067

[9] J. Meyer, L. Dentel, and F. Meunier, "Categorization of Natural Whistled Vowels by Naïve Listeners of Different Language Background", *Frontiers in Psychology*, vol. 8, 25. 2017. 10.3389/fpsyg.2017.00025

[10] J. A. Cohen, "Coefficient of agreement for nominal scales". *Educ. Psychol. Meas.*, 20, pp.37-46. 1960.

[11] Y. Bishop, S. Fienberg, and P. Holland "*Discrete Multivariate Analysis–Theory and Practice"* .Cambridge: MIT Press. 1975.

[12] R Core Team. "R: A language and environment for statistical computing". *R Foundation for Statistical Computing* Vienna, Austria:. 2016. See http:// www.R-project.org

[13] G. Saporta, *Probabilités analyse des données et Statistiques*, Editions TECHNIP, 2011.

[14] T. Hothorn, F. Bretz, P. Westfall "Simultaneous inference in general parametric models". Biom. J., 50, pp. 346–363. 2008 (doi:10.1002/bimj.200810425)

[15] R.V. Lenth "Least-squares means: the R package lsmeans". J. *Stat. Softw.* 69, pp. 1–33. 2016 (doi:10.18637/ jss.v069.i01)

[16] Ch. Mohamed, "*al-Muʿjam al-ʿArabi al-Amazighi = Dictionnaire arabe-amazighe*", Tome 2. Akadimiyat al-Mamlakah al-Maghribiyah = Académie royale du Maroc.1996.

[17] D. François, d M. Elmedlaoui. "*Syllables in Tashlhiyt Berber and in Moroccan Arabic*". Dordrecht: Kluwer. 2002.