Priming Maltese Plurals: Representation of sound and broken plurals in the mental lexicon

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Abstract

We investigate the storage and processing of regular and irregular (sound vs. broken) plural forms in the Maltese lexicon by means of a cross-modal priming study. The results show no significant differences in reaction time between sound and broken plurals, but a different priming effect for sound than for broken plurals. We argue that the different priming effect is a result of the phonological overlap between regular sound singulars and their corresponding plurals forms, while irregular broken singulars and their plurals do not share the same phonological structure. Our results support a single-mechanism model of morphological processing in which both frequency of pattern and morphophonological similarity interact.

Keywords Cross-modal priming · Maltese plurals · morphological processing · single-mechanism

Are regular and irregular complex word forms processed differently in the mental lexicon? The dual-mechanism account on morphological processing that is formulated by Pinker and his colleagues says that they are (Pinker & Prince, 1988; Pinker, 1998). Irregular forms are stored and retrieved as whole word forms, whereas regular complex word forms are composed from a stem and an affix (Pinker & Prince, 1988; Pinker, 1998). Most evidence in support of it comes from languages like English and German, in which such a distinction appears to be sensible at first blush.

The single-mechanism, by contrast, holds that both forms, regulars and irregulars, are stored and processed in the same analogical way (Blevins & Blevins, 2009; Ernestus & Baayen, 2006; Skousen, 1992).

However, evidence has emerged that such a clear cut distinction between regular and irregular morphology cannot always be made (Seidenberg & Plaut, 2014). There is a certain degree of regularity within the irregular forms (Albright & Hayes, 2003), and there is irregularity among the regulars. Maltese, a Semitic language that emerged from a Maghrebi Arabic dialect and that is strongly influenced by Sicilian, Italian and English, is a good language to find relevant data to contribute to this debate, since it has both concatenative and non-concatenative morphology and it shows a great variety of high-frequent and low-frequent regular and irregular plural forms. Is there a relevant distinction between regulars and irregulars, or is it between frequent and infrequent forms?

The dual-mechanism capitalizes on the distinction between regular and irregular word forms. The great majority of complex word forms in English can be considered to consist of a stem and an affix. For example the English past tense form of the verb *walk* is expressed by *-ed* , e.g. *walked.* Because the word form *walked* can be straightforwardly described as a stem *walk* with an added suffix *-ed*, it is assumed that the word form *walked* is derived with the help of a symbolic rule system that does not require access to memory and systematically produces the past tense of regular verb forms in this compositional way.

Irregular forms cannot be straightforwardly described compositionally. The past tense of *drive* is *drove*, the past tense of *sing* is *sang*. The apparent unpredictability of irregular past tense forms led to the assumption that these forms are stored in the mental lexicon and their patterns are generalized to new word forms that show a similarity to the stored forms in memory (Pinker & Prince, 1988; Pinker, 1998). Both mechanisms interact in such a way as that the symbolic rule system is blocked as soon as a word form has its own entry in the mental lexicon and vice versa the rule applies when no word form is provided from memory (Pinker, 1998).

The single-mechanism account, in contrast, assumes a similar processing and storage for regulars and for irregulars. On this account, the relevant distinction among word forms in the mental lexicon is frequency. Frequent word forms are processed faster than infrequent ones, though both are stored in the same way (Albright & Hayes, 2003; Rumelhart & McClelland, 1986).

The way in which word forms are stored in the mental lexicon can be investigated experimentally by means of priming. Priming tasks investigate the influence of one item on another, subsequently, presented item. There are many varieties of priming experiments, one possible paradigm is the cross-modal priming. In this paradigm, participants are presented with auditory primes and visual targets on the screen. This methodology is suited to investigate the storage and processing of word forms in the mental lexicon, since it taps into the modality-independent lexical entry (Marslen-Wilson, Tyler, Waksler & Older, 1994). Several studies recorded reaction times to target words when presented with a morphologically related prime that is either regularly inflected or irregularly inflected (Kielar, Joanisse & Hare, 2008; Marslen-Wilson et al., 1994; Schluter, Al Kaabi, Tucker & Almeida, prep; Sonnenstuhl, Eisenbeiss & Clahsen, 1999). Since we want to contribute to the debate, we use a cross-modal priming paradigm for this study as well.

Studying storage in the mental lexicon. Kielar et al. (2008) report a cross-modal priming experiment on English past tense forms. They use different sets of prime-target pairs. In one of their conditions they use present tense forms as visual targets preceded by morphologically related regular and irregular auditory primes: *walked-WALK* versus *drank-DRINK*. Their results show that both, regular past tense forms and irregular past tense forms show consistent priming effects. They conclude that their results are not compatible with a dual-mechanism model that would predict a priming effect for regulars but not for irregulars.

Sonnenstuhl et al. (1999) did a cross-modal priming experiment on German noun plurals. They compare the priming effect of regular -s plurals, *Kino* - *Kinos* ('cinema - cinemas'), to irregular -er plurals that sometimes involve a change of the stem vowel to a front vowel unless the stem already contains a front vowel: *Mann* - *Männer* ('man - men') versus *Kind* - *Kinder* ('child - children'). 60 target singular nouns were presented with three different primes: identity, control and plural. Their results, contrary to the findings of Kielar et al. (2008) , show a different priming effect between regulars and irregulars: While regulars produced full priming, irregulars show a partial priming only. Thus, Sonnenstuhl et al. (1999) conclude that their data supports a dual-mechanism approach. There is another possible explanation for the different results Sonnenstuhl et al. (1999) find for German regulars and irregulars: The differences might be attributed to the fact that forms like *Kino* - *Kinos* ('cinema - cinemas') show both, a morphological as well as a phonological priming effect, a priming that is based on the morphological and phonological similarity of target and prime items, but forms like *Mann* - *Männer* ('man - men'), on the other hand, show a morphological priming effect only (see also van de Vijver & Baer-Henney, 2014).

However, as mentioned before, further research showed that the line between regular and irregular word forms is less clear that previously thought. English irregular past tense verb forms, for example, show groups of similar patterns. Verbs such as *drive*, *write* and *smite* have past tense forms with an [o]: *drove*, *wrote* and *smote*. Native speakers know about these patterns and use this knowledge to inflect novel verbs (Albright & Hayes, 2003). This is in line with the notions of the "quasiregularity" of the system introduced by Seidenberg & McClelland (1989)(see Seidenberg & Plaut, 2014, for an overview) and "islands of reliability" introduced by Albright & Hayes (2003). An island of reliability can be described as a phonological environment in which a specific morphological change is very likely to occur (see also Zuraw, 2000, 2009, for the Austronesian language Tagalog). Following this, it is possible to build groups of "reliable (ir)regulars" and "unreliable (ir)regulars" (Albright & Hayes, 2003). Even though irregulars in English could be seen as exceptions, these exceptions are not arbitrary but show a shared structure. On a single-mechanism account this fact can be easily incorporated since the same mechanism applies for regulars and irregulars. Both word forms are then part of the same quasiregular system, handled with the same single mechanism. The dual-mechanism account on the other hand focuses on the systematicity of forms. Quasiregularity and islands of reliability then pose a challenge for dual-mechanism accounts. Even though we find productive quasiregular patterns in a language, these are still counted as exceptions because the system is essentially rule governed (Seidenberg & Plaut, 2014).

French (Meunier & Marslen-Wilson, 2004) is divided in conjugational classes and provides a richer palette of morphophonological patterns than English. Research on processing of verbs from different conjugational classes, which are (ir)regular to different degrees, shows that all of them are processed similarly, further casting doubt on a strict separation between regular and irregular forms.

In their experiment, Meunier & Marslen-Wilson (2004) use four different types of French verbs that vary in what they call their "degree of regularity/irregularity" (Meunier & Marslen-Wilson, 2004), e.g. regular forms like *aimer-aimerons* 'to love - we will love' and *amener-amène* 'to bring - I bring' versus irregular forms like *peindre-peignent* 'to paint-they paint' and *boire-buvaient* 'to drink-they drank'. The results of their cross-modal priming experiment with these French verb forms show a similar priming effect for both, regulars and irregulars. These findings again are inconsistent with a classic dual-mechanism model of morphological processing but rather support a single-mechanism model that predicts a similar priming effect for both types of inflectional processes. Meunier & Marslen-Wilson (2004) also suggest a second model for their findings that is a revised version of the dual-mechanism account proposed by Marslen-Wilson & Tyler (1998). This revised account, the so-called neuropsychological account, relies on morphophonological parsing processes. English irregular past tense forms are phonologically unpredictable and differ in this respect from regular past tense forms (Marslen-Wilson & Tyler, 1998). We do not find smaller morphophonological units, e.g. a combination of stems and affixes, whereas regular verb forms show a linear combination of those. As a consequence, irregular words need to be stored separately as full forms and access to these forms does not involve phonological parsing. On this revised dual-mechanism account differences in processing for English past tense verbs are expected (Meunier & Marslen-Wilson, 2004). French irregular verbs, on the contrary, undergo a stem alternation but in addition they are always inflected with a suffix marking person and number (as well as tense and aspect in some cases). That means, irregular verbs in Romance languages still show a morphological concatenation operation and hence the absence of priming effects in Meunier & Marslen-Wilson's (2004) study could be attributed to the morphophonological processes that are involved in this case of regularity within the irregularity (Meunier & Marslen-Wilson, 2004).

A language that further pushes the envelope of regular and irregular patterns is Maltese. Maltese has two types of plurals. Sound plurals are formed by suffixation of any of a number of different suffixes. These plurals are usually considered to be regular (Azzopardi-Alexander & Borg, 1997). Broken plurals are expressed by changing the prosodic structure of the singular, sometimes in combination with a change in vowel quality. There are about eleven different patterns, and broken plurals are considered to be irregular (Azzopardi-Alexander & Borg, 1997). If there are separate mechanisms for regular and irregular morphology, we expect a clear dissociation between sound and broken plurals. If there is a single mechanism, we expect no dissociation between sound and broken plurals.

In this study, we will report data from a cross-modal priming experiment on Maltese noun plurals. Maltese provides an interesting testing ground to investigate the storage of regular and irregular word forms since it shows a split morphology, concatenative and non-concatenative, and a great amount of variation within both systems. Moreover, in Maltese we can differentiate between groups of frequent and infrequent noun plural patterns and thus shed some light on the importance of quasiregularity and islands of reliability for Semitic languages.

In the following chapters we will describe the plural formation in Maltese. We will then focus on the present study and report our findings. Our results, like the results of Kielar et al. (2008) and Meunier & Marslen-Wilson (2004) for English and French, support a single-mechanism model of morphological processing. In addition, will show that the frequency of sound plural suffixes and broken plural patterns plays an important role for the processing of regular and irregular word forms. Moreover we will argue that the greater priming effect for sound plurals we find can be explained with the phonological overlap of singular and plural forms that facilitates the processing of sound plurals. Since singulars that have a broken plural don't share as much material as sound singulars with their corresponding plural forms, priming effects are smaller for these nouns. Taking this into consideration we will conclude that Maltese sound and broken plurals are processed within the same single mechanism despite the different priming effect.

1 Maltese Plurals

Maltese is the national and official language of the Republic of Malta and spoken by about 500.000 people. The Maltese language is classified as a Semitic language that emerged from a Maghrebi Arabic dialect. Due to extensive language contact with Indo-European languages, Maltese developed two fundamentally different ways of expressing the plural of a noun. The so-called *sound plurals* are expressed by one of several different suffixes (Azzopardi-Alexander & Borg, 1997). These are illustrated in table 1, taken from Nieder, Mitterer & van de Vijver (subm).

Table 1: *Maltese sound plural suffixes, taken from Nieder et al. (subm)*

Sound Plural Suffix	**Example**	**Gloss**	**Distribution**
-i	*karta - karti*	'paper'	1244 words
-ijiet	*omm - ommijiet*	'mother'	433 words
-iet	*rixa - rixiet*	'feather'	423 words
-a	*giddieb - giddieba*	'liar'	110 words
-in	*meħlus - meħlusin*	'freed'	91 words
-s	*kuxin - kuxins*	'cushion'	53 words
-at	*triq - triqat*	'street'	52 words
-ien	*sid - sidien*	'owner'	5 words
-n	*baħri - baħrin*	'sailor'	2 words
-jin	*ħati - ħatjin*	'guilty'	1 word
-ejn/ajn	*spalla - spallejn*	'shoulder'	1 word
	sieq - saqajn	'foot'	
-an	*qiegħ - qiegħan*	'bottom'	1 word

The column on the left displays the different Maltese sound plural suffixes. The column 'Example" shows a singular-plural pair for each of the suffixes. Finally, the distribution of sound plural suffixes is illustrated in the rightmost column. This distribution depends on a data set of 3330 nouns from the MLRS Korpus Malti v3.0 (Borg, Fabri, Gatt & Rosner, 2011) that was compiled for an earlier production study on Maltese plurals (Nieder et al., subm). Sound plurals are part of the concatenative morphology of Maltese and can be described as the regular plural forms.

The so-called *broken plurals*, on the other hand, are expressed by a change in the structure of the word itself. The only thing that is retained between a singular and plural form are the consonants that make up the singular and their order. Vowels may be deleted or changed. For example, the singular noun *qattus* 'cat' is pluralized as *qta:tes*, in which the coda consonant of the first syllable in the singular ([t]) is in the onset of the plural, and the short vowel in the first syllable of the singular corresponds to a long vowel in the plural (Azzopardi-Alexander & Borg, 1997). Table 2 is taken from Schembri (2012) and displays all possible broken plural patterns of the Maltese language:

Table 2: *Patterns of distribution of broken plural forms, taken from Schembri (2012)*

Singular	Plural	Gloss	CV Pattern Plural	Distribution
fardal	*fradal*	‘aprons’	CCVVCVC	231 words
birra	*birer*	‘beers’	(C)CVCVC	169 words
kbir	*kbar*	‘big (pl.)’	CCVVC	115 words
ftira	*ftajjar*	‘type of bread (pl.)’	CCVjjVC	42 words
bitħa	*btieħi*	‘yards’	CCVVCV	40 words
sider	*isdra*	‘chests’	VCCCV	12 words
marid	*morda*	‘sick persons’	CVCCV	11 words
għodda	*għodod*	‘tools’	(għ)VCVC	4 words
elf	*eluf*	‘thousands’	VCVC	3 words
għaref	*għorrief*	‘wise men’	CVCCVVC(V)	2 words
għama	*għomja*	‘blind persons’	(għ)VCCV	2 words

Please note that the illustrated frequency distribution of broken plurals is based on Schembri’s (2012) broken plural noun list she compiled for her study. Broken plurals are considered to be the irregular plural forms and are part of the non-concatenative morphology of Maltese.

Previous studies have shown that both morphological systems, concatenative and non-concatenative, are actively used by Maltese native speakers (Drake, 2018b; Nieder et al., subm; Twist, 2006). Moreover, Nieder, Mitterer & van de Vijver’s (subm) results indicate that the frequency of suffixes and patterns plays an important role in shaping the intuitions of native speakers about the Maltese plural formation. Facing the great amount of variation in the Maltese plural system as well as the variable frequency of patterns, an open question we want to address in this paper is how Maltese plural forms are represented in the mental lexicon.

2 Hypotheses

The present study investigates the representation of broken and sound plurals in Maltese by presenting results from a cross-modal priming experiment with frequent and infrequent Maltese plural patterns. Following the different studies (Kielar et al., 2008; Meunier & Marslen-Wilson, 2004; Sonnenstuhl et al., 1999) that were presented earlier in this paper, we can contrast two hypotheses:

- If there is a difference in the speed of processing of our participants between Maltese sound and broken plurals and a different frequency effect, we conclude that regular and irregular plural representation is different, confirming a dual-mechanism account of morphological processing (Pinker & Prince, 1988; Pinker, 1998).
- If there is no difference in reaction times between sound and broken plurals and no different frequency effect for both plural types, both plural forms are processed within the same analogical mechanism, confirming a single-mechanism account of morphological processing (Rumelhart & McClelland, 1986).

3 Methodology

3.1 Participants

Fifty-nine adult native speakers of Maltese (34 women and 25 men) with a mean age of 23.58 years participated in the experiment. They were recruited at the University of Malta with an online sign-up sheet and announcements. All subjects were paid for participation and participated voluntarily in this research. All of them filled in a consent form and a language background questionnaire before the experiment.

3.2 Materials

144 nouns from the MLRS Korpus Malti v3.0 (Gatt & Čéplö, 2013) were used as target items in the experiment. The corpus contains 250 million word token from different genres like parliamentary debates, religious texts or press news and is thus a representative illustration of the Maltese lexicon. The targets were always the singular forms of the nouns. To test for possible frequency effects that are found with Maltese broken and sound plural nouns in earlier studies (Nieder et al., subm; Schembri, 2012), we included two frequent and two infrequent sound plural suffixes as well as two frequent and two infrequent broken plural patterns. We chose the sound plural suffixes -*i* and -*ijiet* to represent the category of high frequent suffixes and the suffixes -*a* and -*at* to represent the category of low frequent suffixes. For the broken plurals we chose the high frequent pattern *CCVVCVC* and *CCVVC* and the low frequent pattern *CCVjjVC* and *CCVVCV*. Frequency was determined based on the findings of Nieder et al. (subm) as well as on the classification for broken plurals in Schembri (2012). See also tables 1 and 2 for an overview.

For all 144 target items we used two types of primes: Corresponding plural primes and phonologically and semantically unrelated control primes with the same plural suffixes or pattern like the corresponding plural word. Target and prime items were roughly matched for their corpus frequency number (instances of million words). In addition, targets were coded for their number of syllables (1-3) and their origin (semitic vs. non-semitic).

Because the participants should not see the same target item twice, two lists were constructed. In each list all targets were used such that half of the targets were presented with plural primes and half of the targets were presented with control primes.

We also included 144 nonce filler items to prevent participants from guessing the purpose of the experiment or developing wrong expectations about the research and to fulfill the requirements of a lexical decision task. The nonce fillers were constructed from existing Maltese singular nouns and had an initial phonological overlap with their corresponding existing words. Fillers were always presented with the corresponding plural forms of the existing singulars that have been used as a base to create nonce words. Table 3 illustrates an example stimulus set.

Table 3: *Example of items that were used in the present reaction time study.*

	PrimeType			
Target	Related Plural	Control Plural	Frequency	Plural Type
kappella	*kappelli*	*politiki*	high	sound
patri	*patrijiet*	*universitajiet*	high	sound
alla	*allat*	*triqat*	low	sound
qattiel	*qattiela*	*halliema*	low	sound
farfett	*friefet*	*xwabel*	high	broken
tifel	*tfal*	*swieq*	high	broken
storja	*stejjer*	*ktajjen*	low	broken
banda	*bnadi*	*ċrieki*	low	broken
vilnu	*vilel*	-	(*filler*)	(*filler*)

Note. The last row displays fillers (target = nonce words, prime = existing plural)

The leftmost column contains different singular nouns that were used as targets in the experiment. The next two columns illustrate the two types of primes that were presented with the targets. Participants either heard a corresponding plural prime or they were primed with a phonologically and semantically unrelated control prime, depending on the two different lists we compiled. The rightmost column contains the coding for the frequency of affixes and patterns. The singular target noun *banda* in the penultimate row, for example, takes the infrequent broken plural pattern CCVVCV and is thus coded as *low frequency broken*. Frequency was not coded for nonce filler items like *vilnu*, displayed in the last row of the table. In addition, fillers were not presented with control primes.

Six practice items were included to familiarize the participants with the procedure. The practice items consisted of two singular targets that have a sound plural form, two singular targets that have a broken plural form and two nonce singular targets. One of the existing singular targets was always presented with the corresponding plural prime, one of them with an unrelated control prime. For nonce targets in the training trial phonologically similar existing plural primes were used.

All items were verified by a Maltese native speaker and were checked with a current dictionary (Bugeja, 2017). If necessary, unclear target items were replaced.

3.3 Procedure

Both types of primes, plural and control, were recorded by a female Maltese native speaker with the software *SpeechRecorder* (Draxler & Jänsch, 2004) in a sound-attenuated booth at the Cognitive Science laboratory at the University of Malta. The recordings were then prepared with Praat (Boersma & Weenink, 2013) for the experiment. Within each recording the word's onset and offset were marked manually. All primes were cut with the help of a Praat script and stored as .wav files.

The experiment was conducted with the software PsychoPy (Peirce, Gray, Simpson, MacAskill, Höchenberger, Sogo, Kastman & Lindelov, 2019) on a Windows computer in a sound-attenuated booth of the Cognitive Science laboratory at the University of Malta. Key responses were collected with a button box. Participants pressed a green button for a real word and a red button for a nonce word. For right-dominant participants the green button was on the right side, for left-dominant participants the green button was on the left side.

Prior to the experiment participants were given consent forms and language background questionnaires in English. After filling in the forms, participants were taken into the booth to read the detailed instructions of the experiment in Maltese. Based on their participant number they were assigned to one of the two lists. They were told that they have to perform a lexical decision task to identify real Maltese words and nonce words. In addition, the researcher pointed out that they are allowed to ask questions and leave the experiment at any time.

The experiment started with a short practice trial to familiarize the participants with the experiment. The test trials started four seconds after these practice trials. Each trial started with a black fixation cross in the middle of the white screen that was displayed for 500ms. The fixation cross was followed by the auditory prime words that were presented by loudspeaker. Immediately after the prime offset the written target was presented for 2000ms in a black font in lower case in the middle of the white screen (ISI = 0 ms). Participants reactions were measured as soon as the target appeared, the next trial followed immediately after the button click. After completing 50 trials in a row the participants had the opportunity to have self-determined breaks. The experiment continued when the participants confirmed that they are ready to continue with a button click.

3.4 Results

Wrong answers for existing words, i.e. a nonce-response, and wrong answers for nonce words, i.e. an existing-response, were removed from the data set (this removed 4.7%, 799 of 16992 data points). In addition, we identified outliers with an intercept only model and removed data points with a residual larger than 2.5 (2.2%, 352 of the remaining 16193 data points).

Table 4 shows the mean reaction times for each experimental condition. The left column contains the description of the different conditions of the experiment. The conditions were annotated as filler or as sound or broken depending on the plural form of the singular target. In addition the type of prime is specified as plural or control for sound and broken conditions only. The second column shows examples for each condition. The word on the left displays a Maltese singular noun that has been used as a target word, the word on the right displays the corresponding plural form for plural conditions or an unrelated plural word for the control conditions. The rightmost column shows the mean reaction times in miliseconds.

Table 4: *Mean reaction times*

Condition	Example	Mean RT
broken, plural prime	*qattus - qtates*	627
sound, plural prime	*omm - ommijiet*	630
broken, control prime	*ballun - fkieren*	670
sound, control prime	*vjaġġ - kuluri*	704
filler	*kapla - kapep*	776

Overall broken plural targets that were presented with their corresponding plural form as prime produced the shortest mean reaction time, but we do not find a significant difference between broken and sound plurals (p=0.163, see table 6).

3.5 Statistical analysis

To test possible factors that could influence the observed reaction times we fitted two linear mixed effect regression models using the `lme4` package (Bates, Mächler, Bolker & Walker, 2015) in the R environment (R Core Team, 2016). Responses to the practice trial items were not included in the analysis. In the models log-transformed reaction times were used as dependent variable. Our independent variables varied across the models and we will list all variables that were used in a model in the corresponding sections of the different models below. We tested seven different independent variables of interest: PLURALTYPE, PRIMETYPE, PATTERNFREQUENCY, ORIGIN, TARGETFREQUENCY, PRIMEFREQUENCY and SYLLABLE.

3.5.1 Coding of variables

The variable PLURALTYPE was coded with the two levels `broken` or `sound` to test for the effect of plural types on the reaction times of our participants. To test the predictions of dual-mechanism accounts, the variable is included in both of our models. PLURALTYPE was entered as numerical contrasts using Helmert coding in the model to avoid convergence problems (`sound` 0.5, `broken` -0.5,).

In the experiment participants were primed with auditory plural primes or control primes. To see if the priming was successful we included the variable PRIMETYPE with the two levels `plural` or `control` in our full model. PRIMETYPE was entered as numerical contrast using Helmert coding again (`plural` 0.5, `control` -0.5).

In her classification for broken plurals Schembri (2012) lists different broken plural patterns along with their frequency. Based on her findings and earlier studies (Nieder et al., subm) we selected two frequent and infrequent sound plural suffixes and two frequent and infrequent broken plural patterns. To test for an effect of frequency the variable PATTERNFREQUENCY with the levels `high` and `low` was created and entered as numerical contrast (`high` 0.5, `low` -0.5).

In addition to the frequency of suffixes and patterns we included the variables TARGETFREQUENCY and PRIMEFREQUENCY in our models. Target and prime frequencies measured as occurrences per million words were obtained by searching the Korpus Malti v.3.0. on the Maltese Language Resource server, MLRS, (Gatt & Čéplö, 2013) for all types.

Maltese is a semitic language with a dual lexicon. Previous research (Drake, 2018b,a; Spagnol, 2011; Twist, 2006) has shown that some speakers are aware of the two morphological systems and therefore tend to produce word forms that match the word's semitic or non-semitic origin during production experiments. To take a possible effect of the word's origin into consideration we included the variable ORIGIN with the two levels `semitic` and `non-semitic`.

The variable SYLLABLE was coded with the levels `1`, `2` and `3`. The variable is necessary to include the possibility that words with a larger number of syllables need a longer reaction time than words that are inherently shorter.

PARTICIPANT and ITEM were always included as random effects in all models. Following (Barr, Levy, Scheepers & Tily, 2013) all possible random slopes were specified and the maximal random effect structure supported by the data was included.

3.5.2 Results: First Lmer Model - Single-Mechanism

A first model with an interaction of PRIMEFREQUENCY and PLURALTYPE was fitted to test the predictions of single and dual-mechanism accounts. A classic dual-mechanism model (Pinker & Prince, 1988; Pinker, 1998) would predict a different frequency effect for sound and broken plurals since regulars are computed online and thus they are not influenced by frequency. If the interaction turns out to be significant, our results would support the classic dual-mechanism account. This first model is necessary to determine if we are dealing with a dual-mechanism or a single-mechanism of morphological processing in Maltese. In a second model we will then include the variables we controlled for in the reaction time experiment to see what factors influenced the reaction times of our participants. Table 5 displays the result of the first model:

Table 5: *lmer model results: effect of the interaction of plural type and word frequency of plural forms on rt*

	Estimate	Std. Err	t-value	p-value
Intercept	6.489808	0.024523	264.645	<2e-16 ***
PRIMEFREQUENCY	-0.031785	0.004920	-6.460	2.97e-10 ***
PLURALTYPE	0.027899	0.022605	1.234	0.218
PRIMEFREQUENCY:PLURALTYPE	0.001253	0.009460	0.132	0.895

The results show no significant interaction of PRIMEFREQUENCY and PLURALTYPE (p = .9). Thus, our data shows no difference in reaction time for the interaction of word frequency and the two plural types broken and sound. The participants did not react faster on frequent broken plurals than on frequent sound plurals. Rather we find a main effect for PRIMEFREQUENCY ($p > .01$) indicating that the word frequency is an important predictor for both plural types. We interpret this as evidence for a single-mechanism model of morphological processing.

3.5.3 Results: Second Lmer Model - Structure of the Single Mechanism

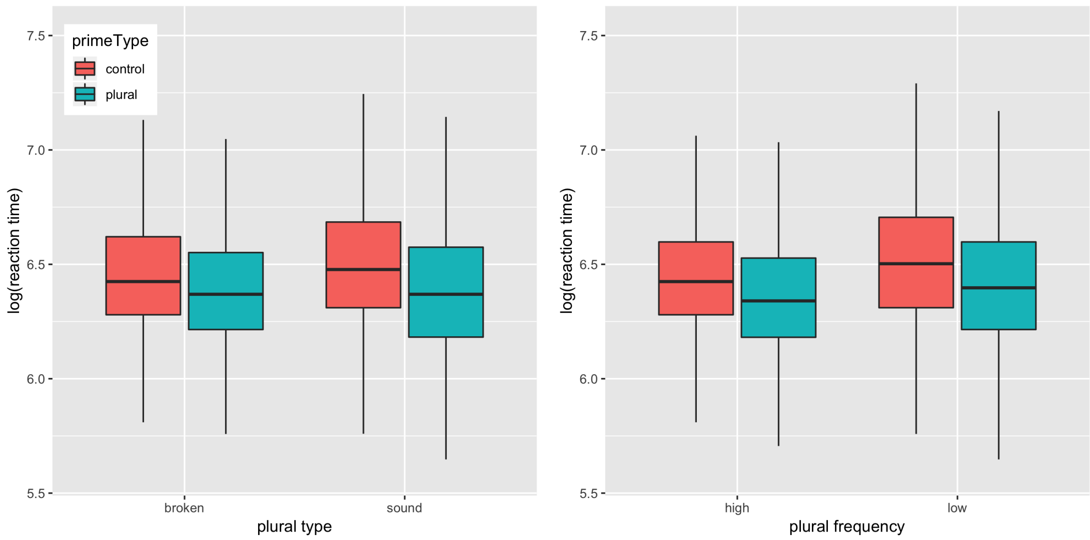
A second linear mixed effect regression model was fitted to investigate what factors determined the observed reaction times for sound and broken plurals in Maltese. All of our variables of interest were included and different two-way interactions were tested. We then simplified the model by excluding all insignificant variables, e.g. variables with a p-value lower than 0.05, leading to final model that contained the variables PatternFrequency, PrimeType, TargetFrequency and PluralType. Table 5 shows the estimates and p-values of the final model.

Table 6: *Summary of the full model*

	Estimate	Std. Error	t-value	p-value
Intercept	6.524636	0.027391	238.202	<2e-16***
PrimeType	-0.094183	0.007289	-12.921	<2e-16***
PatternFrequency	-0.048664	0.016829	-2.892	0.004434 **
PluralType	0.022168	0.015801	1.403	0.162779
TargetFrequency	-0.033620	0.006122	-5.492	1.84e-07 ***
PrimeType:PatternFrequency	0.024779	0.011001	2.252	0.025949 *
PrimeType:PluralType	-0.046186	0.011426	-4.042	0.000135 ***

The final model revealed a significant interaction between PrimeType and PluralType and a significant interaction between PrimeType and PatternFrequency with significant main effects for PrimeType and PatternFrequency. Both interactions are visualized in figure 1 created with the package ggplot2.

Figure 1: *Effect of prime and plural type on reaction times (left); Effect of frequency of patterns and prime on reaction times(right)*



The difference in reaction time between control and plural primes is significantly greater for sound plurals than for broken plurals (see left panel of figure 1), indicating a different priming effect for sound than for broken plurals. We also find a significant main effect for the frequency of patterns and suffixes. Low frequency patterns and suffixes elicited longer reaction times (Estimate: -0.049), see right panel of figure 1. In addition, table 6 revealed a decrease in reaction times the higher the frequency of the target words (Estimate: -0.034). More importantly, like in our model in section 3.5.2 we do not find a significant main effect for PLURALTYPE: Presenting Maltese native speakers with broken or sound plurals did not elicit different reaction times.

3.5.4 Discussion

The results of the two statistical models indicate that Maltese broken and sound plurals are processed in the same way. The absence of a significant effect for the variable PLURALTYPE cannot be attributed to a lack of data points or an insufficient amount of participants. In our study we presented 288 prime-target pairs and we tested 59 participants. This is comparable with the amount of data and participants other studies have used to investigate morphological processing (see Kielar et al., 2008; Meunier & Marslen-Wilson, 2004; Sonnenstuhl et al., 1999). Even though Maltese native speakers reacted equally quickly to both singular targets that were preceded either by a corresponding sound or a corresponding broken plural form, we find a different priming effect for sound than for broken plurals.

The greater priming effect for sound plurals can be explained with the phonological overlap of the singular targets with their sound plural forms (see Kielar et al., 2008, for a discussion). A Maltese singular noun like *kappella* ‘chapel’ has the sound plural form *kappelli* that is build by adding the plural suffix *-i* to the singular stem. Thus, the two words are phonologically identical except for the the added suffix. Pastizzo & Feldman (2002) demonstrated that such a phonological overlap of target and primes facilitates response latencies. Our results are then in line with Pastizzo & Feldman’s (2002) findings and indicate that the given priming effect is driven by the phonological overlap of singular and plural forms and can not be attributed to a different processing mechanism for sound than for broken plural forms. The cross-modal priming paradigm allows to control morphological priming for both word forms, regulars and irregulars, phonological priming, on the other hand, can be hard to find for irregulars especially if these forms are built non-concatenatively like in Maltese.

In addition, our models revealed that the frequency of suffixes and patterns influenced the reaction times of participants significantly, showing that pattern frequency plays an equally important role for the processing of both Maltese plural types.

4 General Discussion & Conclusion

The structure of the mental lexicon has been widely studied by means of priming tasks to investigate the storage of regular and irregular morphological word forms. While some studies found different priming effects for regulars than for irregulars and attribute these differences to a dual-mechanism model of morphological processing (e.g. Sonnenstuhl et al., 1999, for German), other studies reported no differences between regular and irregular word forms and thus conclude a single-mechanism model provides the best explanation for the given data (e.g Kielar et al., 2008; Meunier & Marslen-Wilson, 2004, for English and French).

In this paper we contributed to the debate by presenting the results of a cross-modal priming experiment on Maltese we conducted to explore the processing of frequent and infrequent sound and broken plural patterns in the mental lexicon. The Maltese plural system is divided into two fundamentally different systems: Sound plurals are expressed concatenatively by adding suffixes to the singular stem. Broken plurals are expressed non-concatenatively by stem alternations. In our study we find no significant differences in reaction times for Maltese sound (often considered regular) and broken plurals (often considered irregular). Moreover, there is no different frequency effect for sound than for broken plurals. These findings are not compatible with a classic dual-mechanism model that is proposed by Pinker (1998). On such a dual-mechanism account we would expect a different priming and frequency effect for regulars than for irregulars since both are processed via two distinct mechanisms.

Meunier & Marslen-Wilson (2004) suggest another model to explain the similar behavior the French regular and irregular verbs showed in their study: the revised version of the dual-mechanism account that is proposed by Marslen-Wilson & Tyler (1998).

On this account, the processing of regulars involves a phonological parsing process whereas no such parsing is needed for irregulars, they are stored as whole word forms. English regular and irregular past tense forms are then processed differently, because the irregular past tense forms are not morpho-phonologically predictable (see also Post, Marslen-Wilson, Randall & Tyler, 2008). French verbs, regulars and irregulars, are both morphophonologically complex and therefore Meunier & Marslen-Wilson (2004) do not find a difference in priming.

Following this account, Maltese plural nouns are expected to behave like English past tense forms. Only in the case of sound plurals we find a predictable overt concatenation process. Broken plurals are, on this account, not morphophonologically predictable and are therefore stored as whole word forms. Marslen-Wilson & Tyler's (1998) model would then predict different reaction times for broken than for sound plurals. This is not borne out by the results of this study. Instead, we only find a different priming effect due to the phonological overlap of sound singular and plural forms that is consistent with previous findings on the processing of regular and irregular morphological word forms (Kielar et al., 2008; Pastizzo & Feldman, 2002).The revised dual-mechanism model by Marslen-Wilson & Tyler (1998) is not supported by our findings on Maltese, nor does it take quasiregularity or islands of reliability into account.

We conclude that our results confirm our second hypothesis: There is a single mechanism for both sound and broken plurals. To sum up, we have shown in this study that Maltese, a language with two productive morphological systems, does not show differences in morphological processing between regular and irregular word forms. Instead of morphological regularity, the frequency of patterns and the morphophonological similarity to related word forms are important factors for accessing word forms in the mental lexicon. This suggests that morphological regularity is a gradient rather than a categorical notion. Our data supports a single route for both, broken and sound plurals in Maltese.

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Appendix A Experimental Items

Target	Plural Prime	Control Prime
kappella	kappelli	politiki
pakkett	pakketti	mudelli
student	studenti	voti
vapur	vapuri	argumenti
gazzetta	gazzetti	mumenti
platt	platti	kontinenti
funeral	funerali	karikaturi
ġurnalist	ġurnalisti	sinjali
munita	muniti	attivisti
turist	turisti	tariffi
fabbrika	fabbriki	elementi
vjaġġ	vjaġġi	kuluri
teatru	teatri	villaġġi
grad	gradi	diskorsi
gost	gosti	kolonji
lingwa	lingwi	votanti
karta	karti	esperti
mutur	muturi	kunċerti
ħabs	ħabsijiet	trasmissjonijiet
port	portijiet	klassijiet
kamp	kampijiet	varjazzjonijiet
kor	korijiet	tribujiet
dlam	dlamijiet	viżjonijiet
għan	għanijiet	lokalitajiet

Target	Plural Prime	Control Prime
karru	karrijiet	delegazzjonijiet
patri	patrijiet	universitajiet
garaxx	garaxxijiet	sezzjonijiet
siġġu	siġġijiet	opinjonijiet
premju	premjijiet	missirijiet
omm	ommijiet	trakkijiet
verżjoni	verżjonijiet	professjonijiet
arċisqof	arċisqfijiet	rivalitajiet
passjoni	passjonijiet	kowtijiet
missjoni	missjonijiet	edizzjonijiet
nuċċali	nuċċalijiet	formazzjonijiet
ħmieġ	ħmiġijiet	parkijiet
werriet	werrieta	kerrejja
giddieb	giddieba	daqqaqa
qattiel	qattiela	ħalliema
xandar	xandara	qaddejja
ġardinar	ġardinara	niggieża
ħajjat	ħajjata	qassata
tellief	telliefa	sakranazza
bennej	bennejja	ħakkiema
kittieb	kittieba	nassaba
għalliem	għalliema	kelliema
biċċier	biċċiera	kenniesa
furnar	furnara	qaddiefa

Target	Plural Prime	Control Prime
bexxiex	bexxiexa	ħallieqa
kaħħal	kaħħala	ħaddieda
mexxej	mexxejja	rebbieħa
infermier	infermiera	bejjiegħa
barbier	barbiera	għażżiena
nutar	nutara	għassiesa
xemgħa	xemgħat	qatgħat
setgħa	setgħat	żjarat
waqgħa	waqgħat	frugħat
tebgħa	tebgħat	biżgħat
belgħa	belgħat	refgħat
werqa	werqat	nixxijat
wesgħa	wesgħat	beżgħat
ħsara	ħsarat	laqgħat
kruha	kruhat	żerrigħat
xbieha	xbihat	fergħat
weġgħa	weġgħat	xewqat
bluha	bluhat	qassatat
alla	allat	triqat
mergħa	mergħat	sħanat
taqtigħa	taqtigħat	nixxigħat
idea	ideat	naħat
lifgħa	lifgħat	demgħat
wiżgħa	wiżgħat	tifqigħat

Target	Plural Prime	Control Prime
sikkina	skieken	rziezet
ballun	blalen	fkieren
ċurkett	ċrieket	brieret
ċavetta	ċwievet	bnadar
kappell	kpiepel	bziezen
ġakketta	ġkieket	msielet
farfett	friefet	xwabel
sultan	slaten	tnabar
barmil	bramel	kwiekeb
żarbun	żraben	dħaħen
ġurdien	ġrieden	bsaten
ħanut	ħwienet	ġranet
salib	slaleb	tlielaq
qanpiena	qniepen	dniefel
żiemel	żwiemel	kmamar
bużżieqa	bżieżaq	ħnieżer
tebut	twiebet	frieket
qattus	qtates	dwiefer
tarbija	trabi	qsari
tieqa	twieqi	għelieqi
bidwi	bdiewa	drabi
xitwa	xtiewi	qmura
banda	bnadi	ċrieki
xibka	xbieki	dmija

Target	Plural Prime	Control Prime
ġeru	ġriewi	btieti
xhud	xhieda	qrati
raħal	rħula	ħbula
lejl	ljieli	xtiebi
bitħa	btieħi	lsiera
bieqja	bwieqi	swieni
sidrija	sdieri	flieli
xini	xwieni	ltiema
terħa	trieħi	ġmula
ċumnija	ċmieni	nsara
zalza	zlazi	qfieli
sala	swali	xtieli
reġina	rġejjen	qrejjaq
kċina	kċejjen	ħġejjeġ
froġa	frejjeġ	ġiżirajjen
storja	stejjer	ktajjen
skola	skejjel	dgħajjes
għadira	għadajjar	skrejjen
qbiela	qbejjel	ġlejjeb
xkora	xkejjer	għerejjex
rokna	rkejjen	mkejjen
spiża	spejjeż	knejjes
btala	btajjel	ħlejjaq
ħoss	ħsejjes	flejjes

Target	Plural Prime	Control Prime
għarus	għarajjes	bċejjeċ
ħarifa	ħrejjef	nbejjed
bhima	bhejjem	snajja'
gżira	gżejjer	rwejjaħ
xmara	xmajjar	rqajja'
ħaxix	ħxejjex	żjajjar
qalb	qlub	ġnub
mewt	mwiet	fniek
kelb	klieb	rġiel
xatt	xtut	żjut
ras	rjus	ġlud
xemx	xmux	dnieb
ħabib	ħbieb	swar
tifel	tfal	swieq
sajf	sjuf	ħluq
lupu	lpup	dwieb
zokk	zkuk	rjieħ
ħaruf	ħrief	ġruf
serp	sriep	ċfuf
bejt	bjut	truf
sinna	snien	bjar
but	bwiet	xjuħ
ċint	ċnut	qfief
qawl	qwiel	ħbub

Appendix B Fillers

Target	Plural Prime
sorja	soror
mapta	mapep
pinka	pinen
firsa	firem
borga	borom
faxpa	faxex
vilnu	vilel
sopna	sopop
toqra	toqob
kedna	keded
sodma	sodod
bantu	banek
kaxqa	kaxex
tazna	tazez
fidġa	fided
flotma	flotot
spalmi	spalel
umspanni	umbrelel
balma	balal
kobki	kobob
pizna	pizez
gomra	gomom
gwerpa	gwerer
pjazki	pjazez
rotla	rotot
ġebna	ġebel
borla	boroż
gidna	gideb
polma	poloz
ponpa	ponot
tinra	tined
klikma	klikek
razna	razez
lanfa	laneċ
niċna	niċeċ
berma	bereġ

Target	Plural Prime
kapla	kapep
tarma	taraġ
labsa	labar
kextum	kxaxen
banta	baqar
blokna	blokok
lanka	laned
folm	fran
plakma	plakek
kitna	ktieli
nempu	nemel
għodma	għodod
tabam	tobba
saran	soqfa
basam	ibħra
lsur	ilsna
sefer	ishma
ktun	kotba
makir	morda
ġiler	iġfna
gedħiem	gdiedem
qalzum	qliezet
mena	mirja
ġnul	ġonna
markett	mrietel
marpan	mramad
kolna	kolol
selfien	slielem
qażmien	qżieqeż
folma	folol
fospa	fosos
nasma	nases
sponti	sponoż
qarmi	qwabar
żarpun	żrameġ
pintazz	pniezel

Target	Plural Prime
ajruslan	ajruplani
ambilampa	ambulanzi
fermosija	ferroviji
karaffa	karozzi
lamnezza	lambretti
silp	sinkijiet
frutmiena	fruttieri
karlonna	karrotti
kazotta	kaboċċi
skritzuna	skritturi
wejnar	wejters
nepami	neputijiet
kumil	kuġini
pantu	papri
xarim	xadini
lufampa	lukandi
spiżunżina	spiżeriji
responanz	restoranti
fjuma	fjuri
munkandi	muntanji
għolna	għoljiet
kanfisa	kantini
linz	liftijiet
terlammin	terrazzini
kikhna	kikkri
xufaran	xugamani
purneta	purtieri
samplina	sandlijiet
flizz	flokkijiet
kalmetta	kalzetti
pixnina	pixxini
inspana	intrati
xalamant	xarabanks
swott	swiċċijiet
skriżun	skrivani
mastripanna	mastrudaxxi

Target	Plural Prime
trupna	truppi
denpunt	dentisti
rona	roti
balzamin	ballarini
banpi	banjijiet
anru	anġli
xoll	xokkijiet
velina	veritajiet
barm	bajdiet
penspur	pensjonijiet
kramen	krakers
lezpjumi	lezzjonijiet
jokk	jottijiet
xurr	xuttijiet
kolm	kontijiet
rufim	rubini
ħlup	ħlasijiet
karatiert	kamaleonti
kamisnu	kapitli
masponn	maskotts
metorija	melodiji
optrani	opzjonijiet
skanzji	skandli
triamm	trijonfi
depp	dellijiet
illumpazzjoni	illustrazzjonijiet
kerna	kelmiet
pjaniza	pjaneti
ġorom	ġobnijiet
labda	lampi
saħlam	saħħara
karmazett	kartunetti
torgi	torti
kuċnamera	kuċċarini
ġurkin	ġurnali
rokness	rokketti

Appendix C   Tables and Figures

Table 1: *Maltese sound plural suffixes, taken from Nieder et al. (subm)*

Sound Plural Suffix	Example	Gloss	Distribution
-i	*karta* - *karti*	'paper'	1244 words
-ijiet	*omm* - *ommijiet*	'mother'	433 words
-iet	*rixa* - *rixiet*	'feather'	423 words
-a	*giddieb* - *giddieba*	'liar'	110 words
-in	*meħlus* - *meħlusin*	'freed'	91 words
-s	*kuxin* - *kuxins*	'cushion'	53 words
-at	*triq* - *triqat*	'street'	52 words
-ien	*sid* - *sidien*	'owner'	5 words
-n	*baħri* - *baħrin*	'sailor'	2 words
-jin	*ħati* - *ħatjin*	'guilty'	1 word
-ejn/ajn	*spalla* - *spallejn*	'shoulder'	1 word
	sieq - *saqajn*	'foot'	
-an	*qiegħ* - *qiegħan*	'bottom'	1 word

Table 2: *Patterns of distribution of broken plural forms, taken from Schembri (2012)*

Singular	**Plural**	**Gloss**	**CV Pattern Plural**	**Distribution**
fardal	*fradal*	‘aprons’	CCVVCVC	231 words
birra	*birer*	‘beers’	(C)CVCVC	169 words
kbir	*kbar*	‘big (pl.)’	CCVVC	115 words
ftira	*ftajjar*	‘type of bread (pl.)’	CCVjjVC	42 words
bitħa	*btieħi*	‘yards’	CCVVCV	40 words
sider	*isdra*	‘chests’	VCCCV	12 words
marid	*morda*	‘sick persons’	CVCCV	11 words
għodda	*għodod*	‘tools’	(għ)VCVC	4 words
elf	*eluf*	‘thousands’	VCVC	3 words
għaref	*għorrief*	‘wise men’	CVCCVVC(V)	2 words
għama	*għomja*	‘blind persons’	(għ)VCCV	2 words

Table 3: *Example of items that were used in the present reaction time study.*

	PrimeType			
Target	Related Plural	Control Plural	Frequency	Plural Type
kappella	*kappelli*	*politiki*	high	sound
patri	*patrijiet*	*universitajiet*	high	sound
alla	*allat*	*triqat*	low	sound
qattiel	*qattiela*	*halliema*	low	sound
farfett	*friefet*	*xwabel*	high	broken
tifel	*tfal*	*swieq*	high	broken
storja	*stejjer*	*ktajjen*	low	broken
banda	*bnadi*	*ċrieki*	low	broken
vilnu	*vilel*	-	(*filler*)	(*filler*)

Note. The last row displays fillers (target = nonce words, prime = existing plural)

Table 4: *Mean reaction times*

Condition	Example	Mean RT
broken, plural prime	*qattus - qtates*	627
sound, plural prime	*omm - ommijiet*	630
broken, control prime	*ballun - fkieren*	670
sound, control prime	*vjaġġ - kuluri*	704
filler	*kapla - kapep*	776

Table 5: *lmer model results: effect of the interaction of plural type and word frequency of plural forms on rt*

	Estimate	Std. Err	t-value	p-value
Intercept	6.489808	0.024523	264.645	$<$2e-16 ***
PRIMEFREQUENCY	-0.031785	0.004920	-6.460	2.97e-10 ***
PLURALTYPE	0.027899	0.022605	1.234	0.218
PRIMEFREQUENCY:PLURALTYPE	0.001253	0.009460	0.132	0.895

Table 6: *Summary of the full model*

	Estimate	Std. Error	t-value	p-value
Intercept	6.524636	0.027391	238.202	<2e-16***
PRIMETYPE	-0.094183	0.007289	-12.921	<2e-16***
PATTERNFREQUENCY	-0.048664	0.016829	-2.892	0.004434 **
PLURALTYPE	0.022168	0.015801	1.403	0.162779
TARGETFREQUENCY	-0.033620	0.006122	-5.492	1.84e-07 ***
PRIMETYPE:PATTERNFREQUENCY	0.024779	0.011001	2.252	0.025949 *
PRIMETYPE:PLURALTYPE	-0.046186	0.011426	-4.042	0.000135 ***

Figure 1: *Effect of prime and plural type on reaction times (left); Effect of frequency of patterns and prime on reaction times(right)*