Improved acoustic characterization of prosodic prominence using periodic energy *mass*

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Since Fry's seminal papers on stress (e.g. Fry 1955), the main acoustic cues to prominence in phonetics and phonology have traditionally included both *acoustic intensity* and *duration* as two separate dimensions of prosodic *quantity*. This aspect of prosodic quantity plays a role both in lexical prominence, such as word stress (see overview in Gordon & Roettger 2017) and post-lexical prominence, such as intonational pitch accents (see Baumann & Winter 2018).

Selection: Instead of measuring the intensity of the acoustic signal we suggest a more selective approach in which we measure the *periodic energy* of the signal to reflect the strength of vocalic (voiced) components of speech, excluding voiceless aperiodic components. A measurement of periodic energy relates to pitch intelligibility in perception (House 1990), and is commensurate with functional accounts of syllables as pitch-bearing units, whereby periodic energy can be directly linked with *sonority* (Albert & Nicenboim 2020). Crucially, the periodic energy of speech favors the contribution of harmonic *periodic* components that carry pitch and characterize vocalic elements in the syllabic nuclei, over noisy *aperiodic* components that characterize consonantal portions in the syllabic margins.

Integration: We suggest further that acoustic power and duration should be integrated when attempting to quantify perceived prosodic strength. This can be restated in terms of the problem of measuring power from time series within intervals, essentially asking the following questions: should we track the highest/lowest peak, should we calculate the mean value, or should we sum over the duration of the interval? Those three alternatives differ in how they incorporate time into the measurement of power. Only the latter—summing—truly considers the contribution of time in the perception of quantity (see Turk & Sawusch 1997, Gordon 2004 on the integration of duration and power in prominence, and see Price 1980 on duration effects in perception of sonority). We adopt the summing approach by measuring the area under the periodic energy curve. We term this measurement *mass*.

The integration of power and duration into a single *mass* scale does not mean that language systems and individuals cannot differ in the extent to which they exploit specific aspects of quantity (e.g. increasing duration rather than intensity to enhance prosodic strength). Exploration of these two quantitative dimensions in isolation remains accessible and interesting as before. Mass measurements simply add the integrated quantitative view of prosodic strength, which has been neglected in standard accounts.

Plan: We present methods for obtaining periodic energy and mass measurements using the *ProPer* toolbox Albert et al. 2020, as Figure 1 illustrates. We demonstrate the usefulness of mass measurements with real experimental data from two recent studies: a study of Maltese wh-constructions (Lialiou et al. 2021) and a study on the L2 German intonation of Italian speakers (Sbranna et al. 2021). Maltese speakers exhibit a consistent increase in prosodic strength in locations of stress and focus, while only moderately increasing the strength of unstressed tone-bearing syllables (see Figure 2). In Figure 3, Italian learners of German deaccentuate both given and new information, whereas German speakers deaccentuate only given information and L1 Italian speakers do not deaccentuate at all. In both studies, aggregated mass measurements reveal distinct behaviors that might have otherwise been missed.

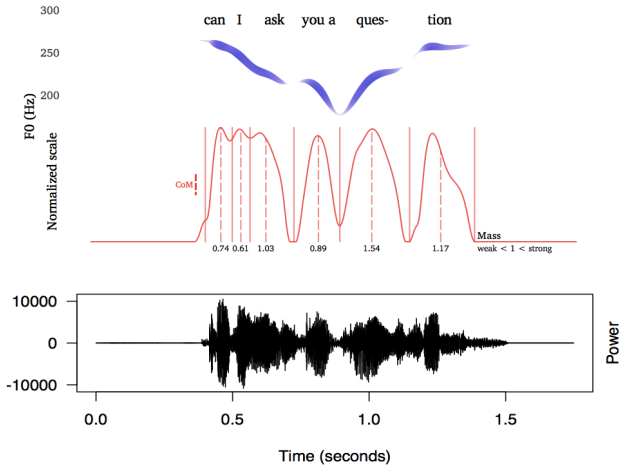


Figure 1 *(left)*. Speech example from the *ProPer* toolbox: Periodic energy plotted in the red curve in the middle, time aligned with the F0 curve in blue at the top and the waveform in black at the bottom. Normalized mass values under the red curve reflect the area under the periodic energy curve within syllabic intervals, between solid vertical boundary lines. Dashed red lines within intervals denote the Center of Mass (CoM). Mass values above 1 reflect a strong syllable. Values below 1 reflect weak syllables.

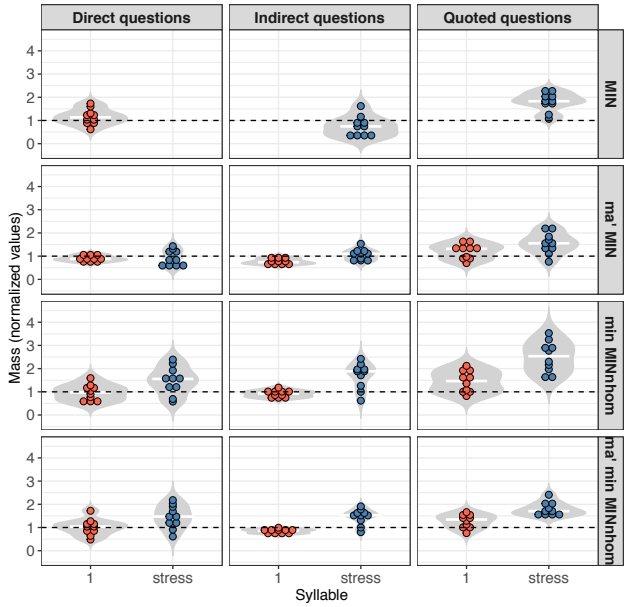
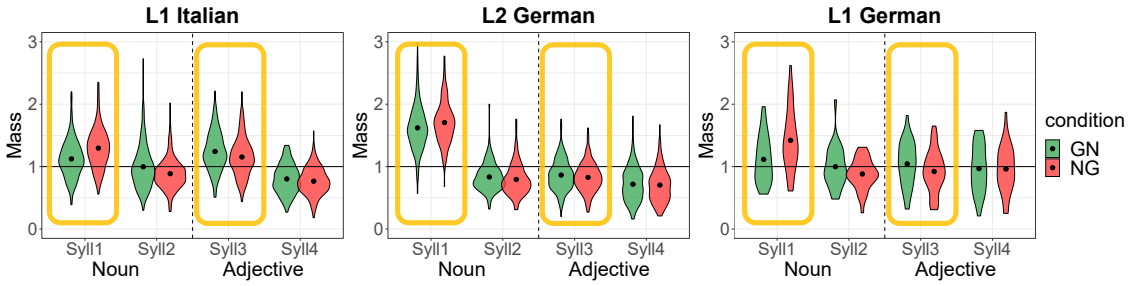


Figure 2 *(left)*. Aggregated mass values of Maltese speakers. Blue data points depict stressed syllables in wh-words of varying size (rows) and type (columns). Red data points depict the initial syllable of the wh-word, which carries a tone in "Direct questions" (left panels) but not in the other modalities: "Indirect questions" in the middle and narrowly focused "Quoted questions" on the right. Data taken from Lialiou et al. (2021).

Figure 3 *(bottom)*. Aggregated mass values comparing Italian and German speakers uttering noun-adjective pairs in two conditions: given-new in green (GN) vs. new-given in red (NG). Deaccentuation patterns are observed between the stressed syllables (in orange frames) by comparing syll3 to syll1. Data taken from Sbranna et al. (2021).



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