Validation of the DuoTone Procedure

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Introduction – the DuoTone procedure

DuoTone is a new procedure for the measurement of hearing thresholds. This procedure has been devised so the subject can run the hearing test himself without being controlled by a test leader (audiologist).

This paper report results from a clinical study that was conducted to compare pure tone audiometrical thresholds in individuals using the standard pure tone audiometry and the DuoTone procedure.

State of the art

The measurement of pure tone hearing thresholds is an established part of clinical hearing assessment protocols. Audiometry is essential for the diagnosis as well as for the fitting of hearing devices, if needed. Audiometry measures the capability of an individual to detect (pure) tones for a number of selected frequencies. The frequencies between 500 and 4.000 Hz are especially important since they fall in the frequency range of normal conversational speech. Therefore, Audiometry is used to identify hearing thresholds, enabling the determination of the degree of a hearing loss.

Audiometry as used in a clinical setting, is a subjective, behavioral assessment of the hearing thresholds, as it relies on the patient response to the pure tone stimuli. A calibrated audiometer with headphones is used. The presentation of the stimuli is controlled by the clinical audiologist and the test person – aka the patient - is expected to respond by pushing a button, raising the hand, giving a voice signal, or, for children, by performing an action in a play situation (play audiometry in children), if a sound is heard.

The quality of the measured pure tone thresholds, that is, by definition, the lowest sound level that was heard by the patient, not only depends on the attentiveness and cooperation of the patient, but also on the experience of the audiologist.

Behavioral audiometry is the gold standard for diagnostic procedures in clinics, but it is time-consuming and requires special equipment and the presence of an audiologist. The DuoTone procedure deals with both issues: easy to use, cheap procedure and an audiologist is not required to perform the audiometric test. As the number of people with a hearing impairment increases, there is more need for a fast, easy and cheap audiometric procedure, not being dependent on the presence of an audiologist.

In most Pure Tone Audiometry test protocols, the presentation of stimuli and the reception and analysis of patient responses are controlled and managed by a test leader. The outcome of the test may depend not only on real hearing threshold levels, but also on test leader skills. However, using well-described methods, like the Hughson-Westlake procedure, the influence of test leader choices can be reduced.

DuoTone procedure

The DuoTone procedure was developed with the intention of having a procedure that runs independently from the direct control by a test leader, i.e. the procedure is fully software controlled.

Two types of stimuli containing pure tones with different frequencies can be presented to the test person. One stimulus (A) contains a continuous tone with the lower frequency (duration of 0.7 s) and the other one (B) contains an intermittent tone (short tones length of 0.22 s, total length of 1 s) three short tones with the higher frequency. A third stimulus (C) does not contain any signal at all and represents the “silent” stimulus. One of the three stimuli is randomly selected and presented to the subject. The silent stimulus (C) is presented with a lower probability than the other two, in order to avoid feelings of uncertainty by the subject.

After each stimulus presentation, a response from the test person is requested by tapping a button on the touch screen with 3 options (visualized), namely one long tone, three short tones or silence (see picture 1). Based on this paradigm, the chance level is 33%.

The silence button plays an important role: the subject knows that there are also silent stimuli. When one of the two stimuli (A) or (B) are delivered at an intensity level below the individual’s threshold, he will not guess between (A) and (B) but select (C). The test comprises several consecutive trials with pairs of stimuli A and B, for instance a 500 Hz (continuous) tone and a 3 kHz (intermittent) tone.

After the test person's response, the next test stimulus is presented automatically after a short delay. If the answer was correct and the test stimulus comprised a tone, the next test stimulus of that specific frequency will be presented at a 5 dB lower intensity. If the response was not correct, the next test stimulus for that frequency will have a 10 dB higher intensity. After 3 reversals (increased presentation level because of a non-heard stimulus) this adaptive procedure is completed and the detection threshold at that particular frequency is calculated. At the end of one trial, two thresholds are available, one for each test frequency.

The advantages of the DuoTone procedure are: self-running procedure on an attractive and modern interactive media device.

Clinical study

Equipment and Methods

The pure tone hearing thresholds were measured using two different methods, one using the standard audiometry and one using the new DuoTone procedure.

Thresholds were measured with the standard audiometer Interacoustics Equinox in combination with a headphone Sennheiser HDA200. The test leaders were experienced clinical audiometrists. They used the Hughson-Westlake procedure and determined hearing thresholds at four frequencies: 500, 1k, 2k, 4k [Hz].

Secondly, hearing thresholds were measured using the DuoTone procedure, implemented on an iPod touch 5th generation, 16GB model. The audio output of the iPod was connected to the audio input of the same clinical audiometer (Equinox) with Sennheiser HDA200 headphones. DuoTone tests were measured in pairs (one low frequency, the other at high frequency) at the same frequencies: 500, 1k, 2k, 4k [Hz]. The sequence of clinical audiometry and the DuoTone procedure was randomized. The order of frequency selection was fixed. For clinical audiometry, this was 1k, 500, 2k and 4kHz. For DuoTone, the first frequency pair was (500;2k) and the second one (1k;4k).

Calibration

The Interacoustics Equinox audiometer was calibrated following regular clinical procedures (ISO 389-1:2000) and its output level was set to 80 dBHL.

The DuoTone procedure is implemented in software on the iPod device and uses an internal dB scale. When no attenuation is applied, the output is 0 dBFS (dB Full Scale).

For each of the four test frequencies 500, 1k, 2k and 4kHz, the iPod was calibrated, based on the dBSPL values at 0 dBFS of the signal. For this calibration, the same equipment was used as for the Equinox clinical calibration (as the headphone was the same). The iPod was connected to the audio input of the Equinox audiometer. Table 1 presents the measured dB SPL values at an input of 0 dBFS, while the output level of the Equinox audiometer was set at 80 dBHL. The second column presents the same data expressed in dB HL.

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Frequency	Output of HDA200 in dB SPL (@ 0 dBFS)	Output of HDA200 in dB HL (@ 0 dBFS)
500	87,5	76,5
1k	90,4	84,9
2k	90,1	85,6
4k	88,8	79,3

Table 1: iPod/HDA200 Calibration

Subjects

All subjects tested during these trials are actual hearing impaired patients that attended regular diagnostic appointments at the audiological clinic. Each patient was tested using the standard clinical tests. Before or after these tests, the patients were informed about an additional experimental measurement and invited to participate in DuoTone testing. Thirteen patients decided to participate; 23 ears could be tested. Five subjects were male and eight were female. Average age was 59,2 years, ranging from 31 to 86 years.

Results

The output data from DuoTone/iPod (in dBFS) were converted into dBHL, using the calibration values from Table 1 (actually the listed values presented in the last column minus 80 dB HL). For each ear and at each test frequency, the difference between the conventional audiometric thresholds and the DuoTone thresholds were calculated. Results are summarized in Table 2, and the histogram of all those differences can be seen in Figure 1. Detailed scatterplots can be found in Figure 2 and Figure 3.

(dB)	All frequencies	500	1k	2k	4k
Average	1,9	3,7	2,0	0,4	1,4
StDev	7,4	8,8	6,4	8,2	6,1
p-value		0.09	0.13	0.65	0.81
N. Samples	91	23	23	23	22

Table 2: Differences between standard audiometric and DuoTone hearing thresholds

Limited differences between standard audiometric and DuoTone hearing thresholds were found, ranging from about 0,4 dB to 3,7 dB with an average difference over all frequencies of 1.9dB. The total data set is summarized in the histogram in Figure 1.

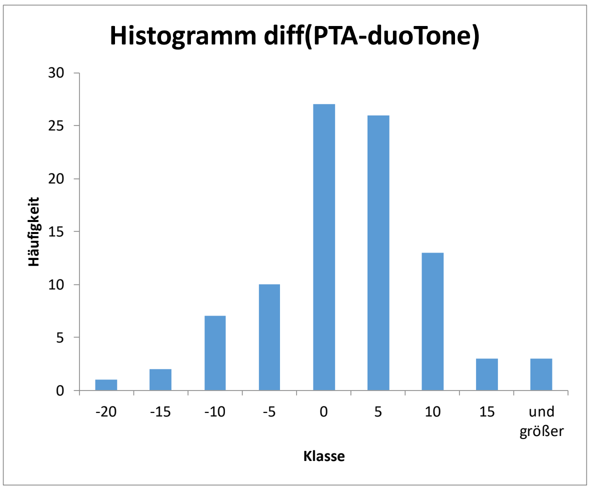

Figure 1: Difference histogram (standard and DuoTone thresholds)

The difference that occurred most frequently, was 0 dB (class from -2.5 till +2.5 dB). Next frequent difference was + 5dB (class from +2.5 till +7.5 dB).

Positive values imply that DuoTone thresholds were lower i.e. suggesting “better hearing”. Note that one outlier value (-42 dB at 4 kHz) was excluded from the analysis.

A permutation test has been performed to assess the statistical significance of this data, under the null hypothesis that the thresholds measured using standard audiometry and DuoTone are the same. The resulting p-values for each frequency can be seen in Table 2. Using a significance level of 5%, the null hypothesis holds at all frequencies (p-value > 0.05), meaning that there is no statistical difference in the hearing thresholds using either standard audiometry or the DuoTone procedure. Figure 2 presents individual data points for the 4 test frequencies.

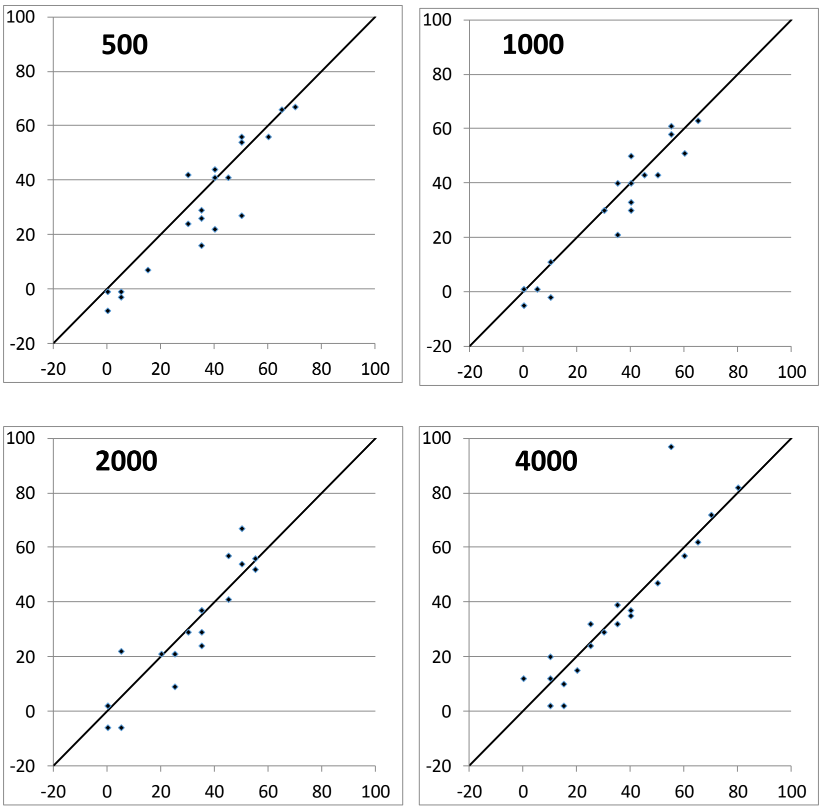

Figure 2: Per frequency scatterplots.

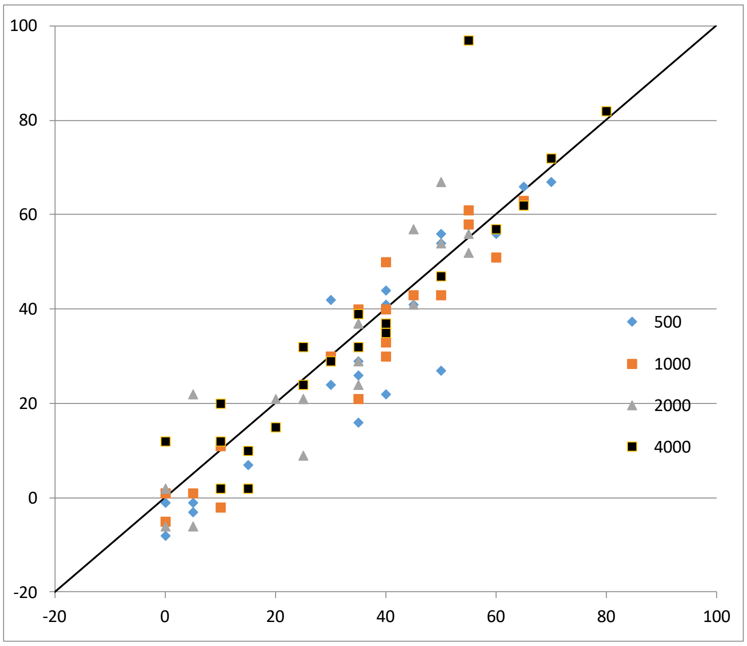

Figure 4: Relation between individual thresholds over the range from 0 dB HL up till over 80 dB HL.

Conclusion

The DuoTone procedure has proven to be a valid procedure to measure the pure tone hearing thresholds as no statistically significant difference was found between the standard clinical procedure and the DuoTone procedure.

This implies that the DuoTone procedure might replace standard audiometry in diagnostic procedures, a self-testing and a self-screening tool, in which the patient runs the procedure autonomously.

Although not statistically significant, we do observe lower hearing thresholds when the DuoTone procedure is used. This is surprising, as clinical audiometry is based only on detection while for correct DuoTone responses an identification task is also needed ("one low" or "three high" tones). That might generate higher "error" rates.

A possible explanation for this phenomenon might be that the DuoTone task is more attractive for the subject/patient causing a higher level of motivation and concentration, leading to lower threshold levels.