Methodology of Two Pods Measurements

Ossiclear System

sounduct

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1. Introduction

Bench characterization of Ossiclear System differs from that of conventional bone conduction devices, as the system combines two transducers positioned on two anatomically distinct sites (the Mastoid and the Condyle) rather than a single Mastoid-coupled transducer. This raises specific methodological challenges for standardized figures of merit such as OVFL60/OVFL90[1] and HFA60/HFA90[2], since no artificial coupler currently exists for the Condyle area. Two complementary approaches are presented. The first couples both transducers to the same artificial Mastoid and applies a theoretical +6 dB coherent-addition correction, validated experimentally by a measured +8 dB increase; this method is standardized and directly comparable to published figures for single-transducer devices, but its off-center dual-transducer setup and the added wiring required introduce measurement imprecision. The second simulates each pod separately on its own anatomically relevant impedance (the artificial Mastoid and published Condyle impedance data), revealing a frequency-dependent complementarity (Condyle-dominant below 300 Hz, Mastoid-dominant above) and a combined gain of +4.71 dB re 1 µN. The two methods are shown to be complementary: the Mastoid-only measurement is retained for specification purposes, while the impedance-based simulation provides physiological insight into the dual-pod frequency response.

Measurements made on Ossiclear System are slightly different from those on any other bone conduction device, as Ossiclear System is composed of two transducers placed on two anatomically different areas. Two measurement methods are presented with their advantages and drawbacks.

[1] OVFL90 and OVFL60 are the Output Vibratory Force Levels developed on the coupler for 90 dB SPL and 60 dB SPL acoustic inputs respectively, full-on gain.

[2] HFA90 and HFA60 (High Frequency Average) are the arithmetic mean of OVFL values at 1,000, 1,600 and 2,500 Hz measured on the coupler for 90 dB SPL and 60 dB SPL acoustic inputs respectively, full-on gain.

2. Ossiclear System's characterization problem

Unlike conventional bone conduction devices, which typically rely on a single transducer, Ossiclear System incorporates two active transducer units positioned at different anatomical locations. This dual-pod configuration raises specific methodological considerations for bench testing. The most precise approach would be to work with an artificial Mastoid such as Brüel & Kjær type 4930 and its equivalent on the Condyle area. However, to the best of our knowledge, no such equivalent exists. Two options are then available:

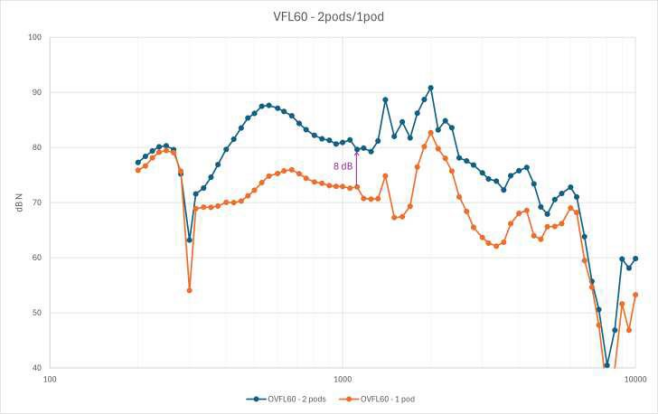
- Measurement and theory of using two simultaneously active transducers coupled to the artificial Mastoid.
- Theory of one transducer placed on the Mastoid area and one on the Condyle area.

2.1. Two transducers on the artificial Mastoid

Direct measurement would require the artificial Mastoid to accommodate two transducers simultaneously, a configuration for which it is not designed and which could introduce uncontrolled mechanical interactions and measurement bias. To avoid such sources of error, the mathematical approach was selected.

Accordingly, measurements were first performed on a single pod. The total vibratory force corresponding to the dual-pod configuration was then estimated by applying a 6 dB correction factor, based on the assumption of coherent addition of two identical force sources. This relationship follows from the logarithmic definition of force level, where doubling the force amplitude results in an increase of ,$20 \times \log_{10}(2)$ corresponding to approximately 6 dB. Under this assumption, the combined force level can be expressed as the single-pod force level increased by 6 dB.

To validate this mathematical approach, a modified experimental configuration was implemented to approximate a simultaneous dual-pod measurement. In this setup, the electrical connections of the anterior transducer were extended, allowing both the anterior and posterior transducers to be driven concurrently while mechanically coupled to the same artificial Mastoid. This configuration enabled verification that the measured force levels were consistent with the theoretical 6 dB increase predicted by the model, supporting the validity of the adopted methodology.



The comparison between one transducer and two in-phase transducers shows an average increase of +8 dBN. In this test configuration, the transducers are not positioned in the center of the artificial Mastoid but have to be off-center, unlike in the standard test bench usage protocol. As a result, this setup cannot perfectly represent the absolute output of the final device. This is the reason why, in normal operation, the output is specified and measured at a single vibration point.

Nevertheless, this experiment provides a clear validation of the theoretical behavior. From a mathematical standpoint, doubling coherent vibration sources is expected to produce an increase of +6 dBN. Here, the measured increase of approximately +8 dBN (±2 dB) confirms this principle.

For specification purposes, the value of +6 dBN is retained.

2.2. One transducer on the Mastoid area and one transducer on the Condyle area

The mechanical impedance of the Mastoid area can be obtained directly from the Brüel & Kjær artificial Mastoid, while the impedance of the Condyle area is derived from data reported in the scientific literature[3]. Comparison of these two impedances reveals a significant gap between the Mastoid and Condyle sites, confirming that the Mastoid-only dual-transducer measurement described above (2.1) provides a good approximation, with values comparable to established norms, but remains incomplete, as it does not capture the distinct mechanical characteristics of each anatomical area.

[3] Yafei Nie et al., "Measurement and modeling of the mechanical impedance of human Mastoid and Condyle," *The Journal of the Acoustical Society of America* 151, no. 3 (2022): 1434–48, https://doi.org/10.1121/10.0009618.

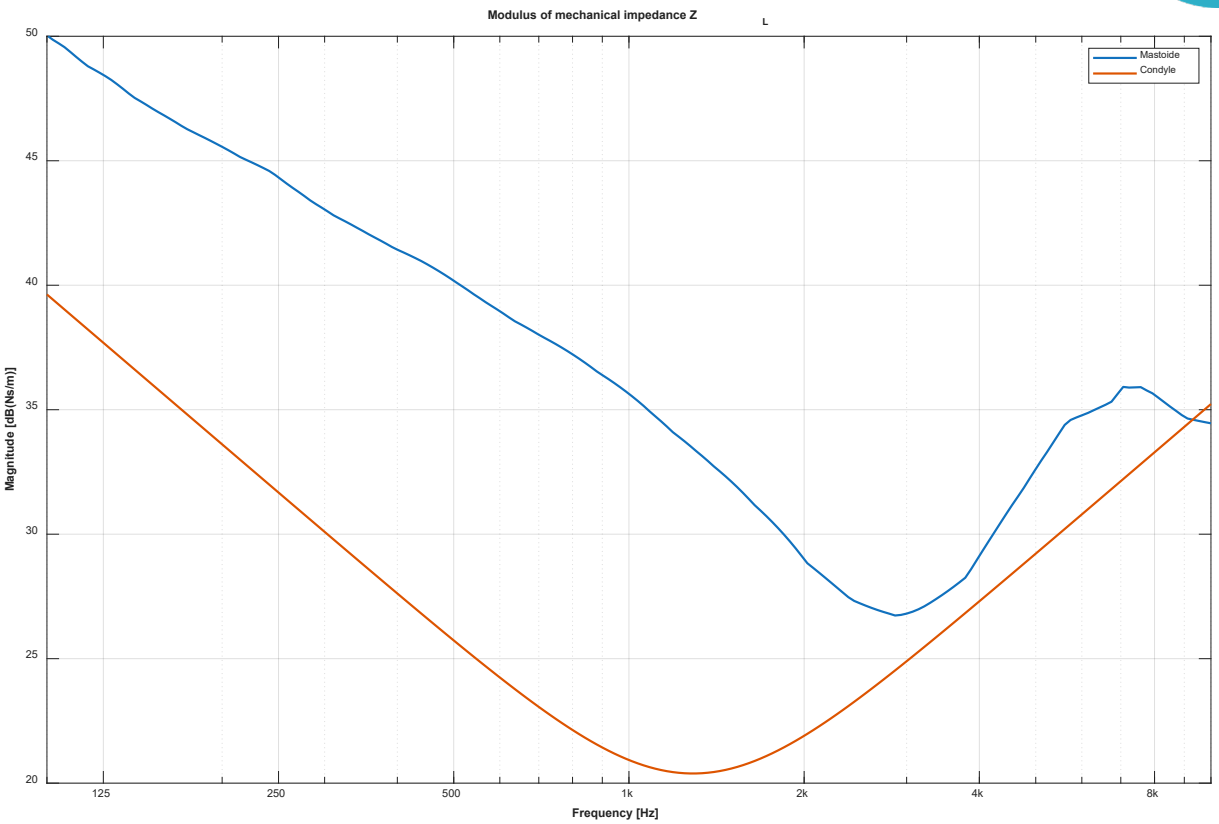


FIGURE 1. MECHANICAL IMPEDANCE OF THE MASTOID AND CONDYLE AREAS. MASTOID IMPEDANCE EXTRACTED FROM THE BRÜEL & KJÆR ARTIFICIAL MASTOID AND CONDYLE IMPEDANCE SIMULATED WITH DATA FROM NIE ET AL. (2022)[4].

The behavior of the system was therefore simulated separately on each of these two impedances. This simulation reveals a fundamental difference in behavior between the Mastoid and Condyle pods: the Condyle pod performs better at low frequencies (up to approximately 300 Hz), while the Mastoid pod delivers stronger output across the remainder of the frequency range. The total force applied to the skull can then be obtained by summing the contributions of the two pods, yielding a higher combined force than the Mastoid pod alone (+4.71 dB re 1 µN).

[4] Nie et al., “Measurement and modeling of the mechanical impedance of human Mastoid and Condyle.”

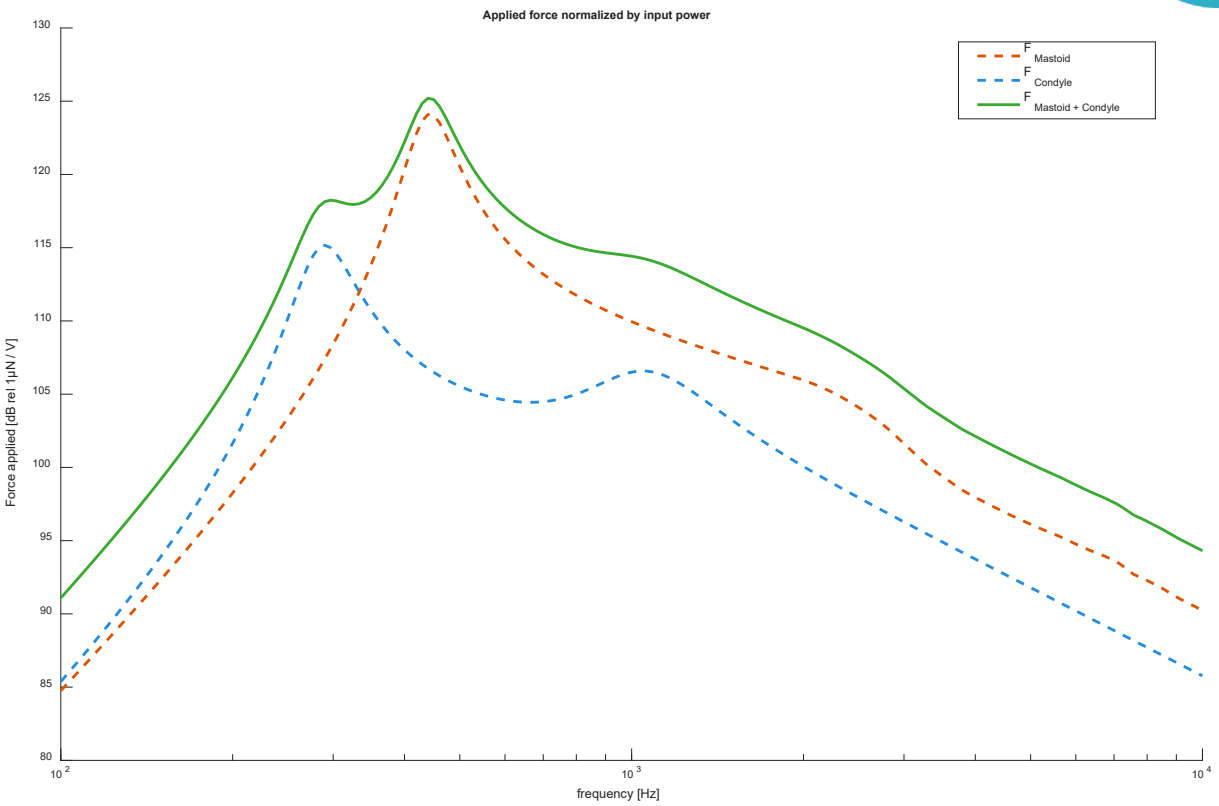


FIGURE 2. SIMULATED FORCE APPLIED BY OSSICLEAR SYSTEM AT THE MASTOID, THE CONDYLE, AND THE COMBINED MASTOID–CONDYLE CONFIGURATION, WITHOUT FREQUENCY-DEPENDENT GAIN.

3. Discussion

The two methods presented above address the same problem but rely on fundamentally different assumptions and consequently yield different types of information.

The direct measurement of two transducers on the artificial Mastoid (2.1) has the advantage of being an actual physical measurement, performed under conditions that closely follow the standard test protocol used for single-transducer bone conduction devices, which makes the resulting +6 dB correction directly comparable to the figures of merit used in the domain. However, this method is inherently imprecise for two reasons. First, both transducers had to be coupled to the same Mastoid-type artificial coupler, which does not reproduce the exact mechanical behavior of the Condyle area on which the second pod is normally placed in the final device; although the measurement was performed in compliance with the standard, the resulting +8 dB value should therefore be interpreted with caution, primarily as supporting evidence for the theoretical coherent-addition model (+6 dB) rather than as a direct measurement of the real dual-pod, dual-area configuration. Second, extending the electrical connection of the anterior transducer to allow simultaneous driving of both units may have altered its electrical loading and, in turn, its mechanical output, introducing an additional source of uncertainty in the measured values.

The impedance-based approach (2.2), in contrast, does not attempt to physically reproduce the dual-pod configuration on a single coupler; instead, it simulates the behavior of each pod on its own anatomically relevant impedance, i.e. the artificial Mastoid for the posterior pod, and published Condyle impedance data for the anterior pod. This method captures a fundamental difference in behavior between the two areas: the Condyle pathway dominates at low frequencies (up to approximately 300 Hz), while the Mastoid pathway provides higher output across the rest of the frequency range. Summing the two contributions yields a combined force gain of +4.71 dB re 1 µN over the Mastoid pod alone. This result is lower than the +6 dB assumed for two identical Mastoid-type sources, which is consistent with the Condyle transducer being mechanically less efficient than the Mastoid one outside the low-frequency region, and therefore contributing less than a truly "identical" second source would. This approach provides a more physiologically realistic, frequency-resolved picture of the dual-pod system, at the cost of relying on Condyle impedance values drawn from the literature rather than measured on the same bench and under the same conditions as the Mastoid data. This introduces uncertainty related to inter-study methodological differences and anatomical variability between individuals.

Taken together, the two methods are complementary rather than interchangeable. The Mastoid-only dual-transducer measurement (2.1) offers a standardized, experimentally validated estimate, directly comparable to figures reported for single-transducer bone conduction devices; although the measured increase was +8 dB, the more conservative +6 dB theoretical coherent-addition value is retained for specification purposes. The impedance-based simulation (2.2) cannot replace this specification value but provides essential insight into the frequency-dependent complementarity between the Mastoid and Condyle pathways, showing that the dual-pod configuration does not merely add force uniformly across frequencies but redistributes it according to the mechanical properties of each anatomical

site. Further work using a dedicated Condyle coupler, should one become available, would allow direct validation of the impedance-based estimate and reconciliation of the two approaches.