**Supplementary Table 1.** Demographic and clinical information of all subjects.

| Sub. ID | Age | Sex | Handed-ness | Main Symptom | Disease Duration (yrs) | UPDRS-III OFF/ON levodopa | DBS Lead | Sound Condition |
|---|---|---|---|---|---|---|---|---|
| 1 | 62 | M | R | FOG | 12 | 27/4 | Medtronic 3389 | Off |
| 2 | 60 | M | R | FOG | 8 | 52/30 | Medtronic 3389 | Off |
| 3 | 59 | M | R | tremor, bradykinesia, dyskinesia | 7 | 53/18 | Boston Scientific DB-2202 | Off/On |
| 4 | 64 | F | R | rigidity, tremor, FOG | 16 | 66/36 | Boston Scientific DB-2202 | Off/On |
| 5 | 59 | M | R | fluctuations, tremor | 14 | 36/8 | Medtronic 3389 | Off/On |
| 6 | 56 | M | L | fluctuations, dyskinesia | 7 | 42/26 | Medtronic 3389 | Off/On |
| 7 | 62 | M | R | tremor, rigidity, dyskinesia, mild FOG | 12 | 59/15 | Medtronic 3389 | Off/On |
| 8 | 71 | M | R | tremor, FOG | 15 | 36/18 | Boston Scientific DB-2201 | Off/On |
| 9 | 61 | M | R | rigidity | 9 | 33/11 | Medtronic 3389 | Off/On |
| 10 | 57 | M | R | tremor, FOG | 12 | 49/18 | Boston Scientific DB-2201 | Off/On |
| 11 | 59 | M | R | tremor, mild FOG | 10 | 28/8 | Boston Scientific DB-2201 | Off/On |
| 12 | 59 | M | R | fluctuations, mild FOG | 22 | 23/6 | Medtronic 3389 | Off |
| 13 | 65 | M | R | tremor | 8 | 16/8 | Medtronic 3389 | Off |

F, female; M, male; L, left; R, right; FOG, freezing of gait; Off, sound off; On, sound on.

**Supplementary Table 2.** Significant test for the *β*-HFO PACs with sound conditions (three levels, Before, On and After) as the fixed factor.

| Index | df | SS | MS | F-Value | P-Value |
|---|---|---|---|---|---|
| *Lβ*-HFO | 2 | 6.61e-8 | 3.30e-8 | 12.42 | **<.0001** |
| *Hβ*-HFO | 2 | 2.12e-8 | 1.06e-8 | 6.42 | **0.0020** |

Significant *p*-values are emboldened.

**Supplementary Table 3.** Statistical results for PACs in twenty-one different frequency pairs. Fixed factors include sound (three levels, Before, On and After) and lateral (three levels, Bi., Contra. and Ipsi.) conditions.

| PAC | Factor | df | SS | MS | F-Value | P-Value |
|---|---|---|---|---|---|---|
| *δ - θ* | Sound | 2 | 7e-6 | 0.0000035 | 1.9136 | 0.1485 |
| | Lateral | 2 | 2.03e-5 | 0.0000101 | 5.5410 | **0.0041** |
| | Sound*Lateral | 4 | 2.19e-6 | 5.4728e-7 | 0.2990 | 0.8786 |
| *δ - α* | Sound | 2 | 8.18e-6 | 4.0905e-6 | 1.7070 | 0.1824 |
| | Lateral | 2 | 1.80e-5 | 9.0043e-6 | 3.7576 | **0.0239** |
| | Sound*Lateral | 4 | 2.44e-6 | 6.1055e-7 | 0.2548 | 0.9067 |
| *δ - Lβ* | Sound | 2 | 9.24e-6 | 4.60e-6 | 5.75 | **0.0034** |
| | Lateral | 2 | 2.11e-5 | 1.05e-5 | 13.13 | **<.0001** |
| | Sound*Lateral | 4 | 1.42e-6 | 3.56e-7 | 0.44 | 0.7777 |
| *δ - Hβ* | Sound | 2 | 1.73e-5 | 8.63e-6 | 19.83 | **<.0001** |
| | Lateral | 2 | 1.88e-5 | 9.38e-6 | 21.55 | **<.0001** |
| | Sound*Lateral | 4 | 2.91e-6 | 7.28e-7 | 1.67 | 0.1549 |
| *δ - Lγ* | Sound | 2 | 1.50e-5 | 7.49e-6 | 31.44 | **<.0001** |
| | Lateral | 2 | 1.15e-5 | 5.77e-6 | 24.21 | **<.0001** |
| | Sound*Lateral | 4 | 1.28e-6 | 3.20e-7 | 1.34 | 0.2531 |
| *δ - Hγ* | Sound | 2 | 9.05e-6 | 4.53e-6 | 30.35 | **<.0001** |
| | Lateral | 2 | 6.30e-6 | 3.15e-6 | 21.12 | **<.0001** |
| | Sound*Lateral | 4 | 1.16e-6 | 2.89e-7 | 1.94 | 0.1027 |
| *θ - α* | Sound | 2 | 2.46e-7 | 1.23e-7 | 1.76 | 0.1737 |
| | Lateral | 2 | 1.02e-6 | 5.10e-7 | 7.28 | **0.0008** |
| | Sound*Lateral | 4 | 2.18e-7 | 5.45e-8 | 0.78 | 0.5403 |
| *θ - Lβ* | Sound | 2 | 5.63e-7 | 2.81e-7 | 1.34 | 0.2627 |
| | Lateral | 2 | 1.73e-6 | 8.64e-7 | 4.11 | **0.0169** |
| | Sound*Lateral | 4 | 7.90e-7 | 1.98e-7 | 0.94 | 0.4399 |
| *θ - Hβ* | Sound | 2 | 1.44e-6 | 7.21e-7 | 9.98 | **<.0001** |
| | Lateral | 2 | 2.10e-6 | 1.05e-6 | 14.54 | **<.0001** |
| | Sound*Lateral | 4 | 3.19e-7 | 7.98e-8 | 1.10 | 0.3536 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *θ - Lγ* | Sound | 2 | 1.87e-6 | 9.33e-7 | 18.36 | **<.0001** |
| | Lateral | 2 | 1.96e-6 | 9.81e-7 | 19.31 | **<.0001** |
| | Sound*Lateral | 4 | 1.74e-7 | 4.34e-8 | 0.86 | 0.4908 |
| *θ - Hγ* | Sound | 2 | 2.40e-6 | 1.20e-6 | 29.71 | **<.0001** |
| | Lateral | 2 | 1.67e-6 | 8.37e-7 | 20.71 | **<.0001** |
| | Sound*Lateral | 4 | 1.77e-7 | 4.43e-8 | 1.10 | 0.3579 |
| *α- Lβ* | Sound | 2 | 1.43e-7 | 7.16e-8 | 9.38 | **<.0001** |
| | Lateral | 2 | 1.85e-7 | 9.27e-8 | 12.16 | **<.0001** |
| | Sound*Lateral | 4 | 3.13e-8 | 7.84e-9 | 1.03 | 0.3923 |
| *α- Hβ* | Sound | 2 | 3.08e-7 | 1.54e-7 | 7.26 | **0.0008** |
| | Lateral | 2 | 5.02e-7 | 2.51e-7 | 11.85 | **<.0001** |
| | Sound*Lateral | 4 | 6.38e-8 | 1.59e-8 | 0.75 | 0.5568 |
| *α- Lγ* | Sound | 2 | 5.57e-7 | 2.79e-7 | 15.82 | **<.0001** |
| | Lateral | 2 | 6.99e-7 | 3.40e-7 | 19.85 | **<.0001** |
| | Sound*Lateral | 4 | 5.99e-8 | 1.50e-8 | 0.85 | 0.4940 |
| *α- Hγ* | Sound | 2 | 1.19e-6 | 5.94e-7 | 30.19 | **<.0001** |
| | Lateral | 2 | 8.68e-7 | 4.34e-7 | 22.08 | **<.0001** |
| | Sound*Lateral | 4 | 1.29e-7 | 3.21e-8 | 1.63 | 0.1642 |
| *Lβ- Hβ* | Sound | 2 | 5.07e-8 | 2.54e-8 | 4.94 | **0.0075** |
| | Lateral | 2 | 7.63e-8 | 3.82e-8 | 7.42 | **0.0007** |
| | Sound*Lateral | 4 | 1.93e-8 | 4.84e-9 | 0.94 | 0.4399 |
| *Lβ- Lγ* | Sound | 2 | 8.41e-8 | 4.21e-8 | 5.84 | **0.0031** |
| | Lateral | 2 | 2.16e-7 | 1.08e-7 | 15.00 | **<.0001** |
| | Sound*Lateral | 4 | 3.54e-8 | 8.84e-9 | 1.23 | 0.2984 |
| *Lβ- Hγ* | Sound | 2 | 3.84e-7 | 1.92e-7 | 16.33 | **<.0001** |
| | Lateral | 2 | 2.43e-7 | 1.22e-7 | 10.34 | **<.0001** |
| | Sound*Lateral | 4 | 3.01e-8 | 7.53e-9 | 0.64 | 0.6341 |
| *Hβ- Lγ* | Sound | 2 | 1.76e-8 | 8.78e-9 | 6.81 | **0.0012** |
| | Lateral | 2 | 3.17e-8 | 1.59e-8 | 12.30 | **<.0001** |
| | Sound*Lateral | 4 | 1.34e-8 | 3.35e-9 | 2.60 | **0.0354** |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Hβ- Hγ* | Sound | 2 | 1.16e-7 | 5.82e-8 | 14.98 | **<.0001** |
| | Lateral | 2 | 7.35e-8 | 3.67e-8 | 9.46 | **<.0001** |
| | Sound*Lateral | 4 | 1.67e-8 | 4.18e-9 | 1.08 | 0.3674 |
| *Lγ - Hγ* | Sound | 2 | 1.63e-8 | 8.14e-9 | 16.32 | **<.0001** |
| | Lateral | 2 | 9.24e-9 | 4.62e-9 | 9.27 | **0.0001** |
| | Sound*Lateral | 4 | 7.75e-10 | 1.94e-10 | 0.39 | 0.8169 |

Significant *p*-values are emboldened.

**Supplementary Table 4.** Significant tests for PLVs between different pairs of frequency bands with the step-phases as the fixed factor (four levels, Seg. 1, Seg. 2, Seg. 3 and Seg. 4).

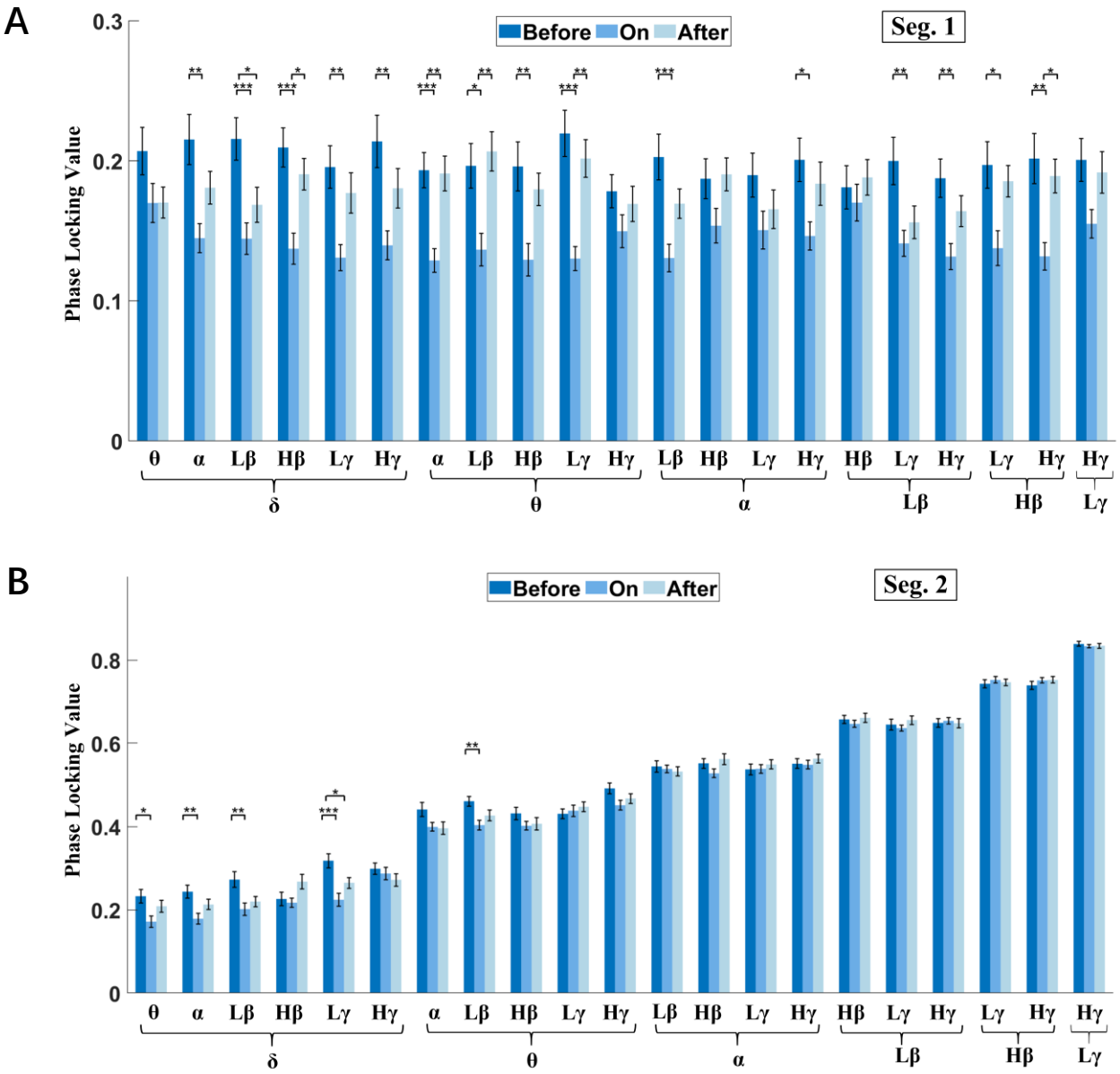
| Pair | df | SS | MS | F-Value | P-Value |
|---|---|---|---|---|---|
| *δ - θ* | 3 | 0.08 | 0.03 | 1.84 | 0.1385 |
| *δ - α* | 3 | 0.11 | 0.04 | 2.71 | **0.0443** |
| *δ - Lβ* | 3 | 0.36 | 0.12 | 8.33 | **<.0001** |
| *δ - Hβ* | 3 | 0.62 | 0.21 | 15.35 | **<.0001** |
| *δ - Lγ* | 3 | 1.64 | 0.55 | 39.40 | **<.0001** |
| *δ - Hγ* | 3 | 1.82 | 0.61 | 41.86 | **<.0001** |
| *θ - α* | 3 | 8.55 | 2.85 | 244.19 | **<.0001** |
| *θ - Lβ* | 3 | 8.53 | 2.84 | 250.96 | **<.0001** |
| *θ - Hβ* | 3 | 8.83 | 2.94 | 239.22 | **<.0001** |
| *θ - Lγ* | 3 | 8.75 | 2.92 | 258.45 | **<.0001** |
| *θ - Hγ* | 3 | 13.26 | 4.42 | 459.42 | **<.0001** |
| *α - Lβ* | 3 | 19.18 | 6.39 | 699.10 | **<.0001** |
| *α - Hβ* | 3 | 19.30 | 6.43 | 684.03 | **<.0001** |
| *α - Lγ* | 3 | 19.54 | 6.51 | 651.33 | **<.0001** |
| *α - Hγ* | 3 | 20.16 | 6.72 | 685.95 | **<.0001** |
| *Lβ - Hβ* | 3 | 31.88 | 10.63 | 1390.18 | **<.0001** |
| *Lβ - Lγ* | 3 | 32.69 | 10.90 | 1287.51 | **<.0001** |
| *Lβ - Hγ* | 3 | 33.63 | 11.21 | 1639.12 | **<.0001** |
| *Hβ - Lγ* | 3 | 44.92 | 14.97 | 2104.43 | **<.0001** |
| *Hβ - Hγ* | 3 | 45.53 | 15.18 | 2217.08 | **<.0001** |
| *Lγ- Hγ* | 3 | 58.63 | 19.54 | 4243.11 | **<.0001** |

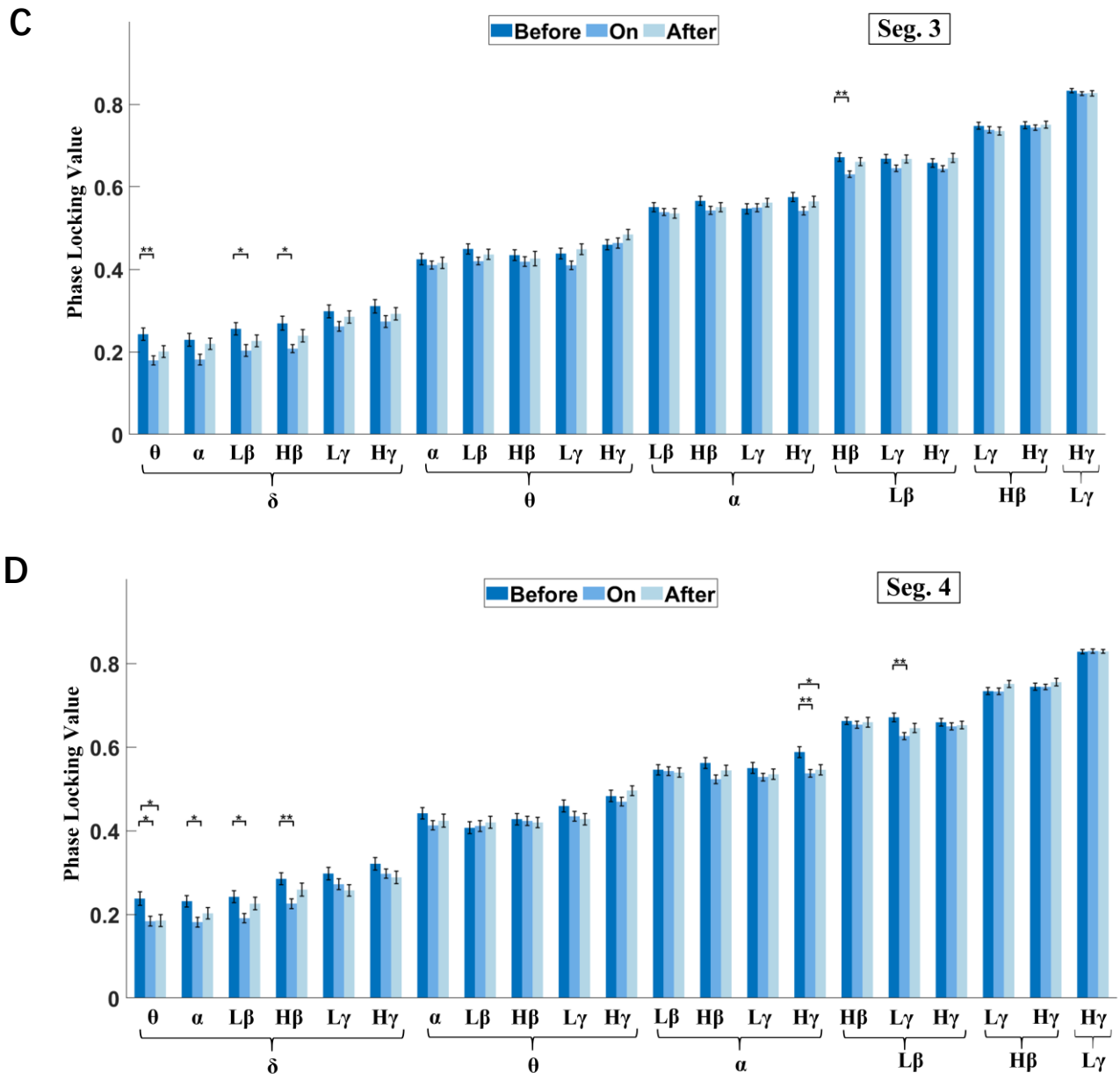
Significant *p*-values are emboldened.

**Supplementary Table 5.** Significant tests for GPM amplitude of STN-LFP in different frequency bands with the sound conditions (three levels, Before, On and After) as the fixed factor.

| Index | df | SS | MS | F-Value | P-Value |
|---|---|---|---|---|---|
| $\delta$ | 2 | 4.88e-4 | 2.44e-4 | 0.10 | 0.9061 |
| $\theta$ | 2 | 8.32e-3 | 4.16e-3 | 1.29 | 0.2786 |
| $\alpha$ | 2 | 8.43e-3 | 4.21e-3 | 1.85 | 0.1609 |
| $L\beta$ | 2 | 8.43e-3 | 4.21e-3 | 1.29 | 0.2773 |
| $H\beta$ | 2 | 4.66e-2 | 2.33e-2 | 4.56 | **0.0117** |
| $L\gamma$ | 2 | 1.33e-3 | 6.64e-4 | 1.51 | 0.2245 |
| $H\gamma$ | 2 | 8.56e-4 | 4.28e-4 | 1.68 | 0.1888 |

Significant *p*-values are emboldened.


A
Before On After
Seg. 1
Phase Locking Value
0.3
0.2
0.1
0
θ α Lβ Hβ Lγ Hγ α Lβ Hβ Lγ Hγ Lβ Hβ Lγ Hγ Hβ Lγ Hγ Lγ Hγ Hγ
δ θ α Lβ Hβ Lγ
B
Before On After
Seg. 2
Phase Locking Value
0.8
0.6
0.4
0.2
0
θ α Lβ Hβ Lγ Hγ α Lβ Hβ Lγ Hγ Lβ Hβ Lγ Hγ Hβ Lγ Hγ Lγ Hγ Hγ
δ θ α Lβ Hβ Lγ




**Supplementary Figure 1.** Comparisons of PLVs in different pairs of frequency bands among the three different sound conditions, wherein each 2-s complete gait cycle was parsed into four 0.5-s step-phases, including (**A)** contralateral heel strike (Seg. 1), (**B**) contralateral foot stand (Seg. 2), (**C**) ipsilateral heel strike (Seg. 3), and (**D)** ipsilateral foot stand (Seg. 4).