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# The Newcastle Auditory Battery (NAB) A temporal and spatial test battery for use on adult naïve subjects

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**Abstract**

A battery of tests for assessing the perception of temporal and spatial acoustic cues is described, together with a software platform for implementing the battery. The software runs on a personal computer either with a sound card or with widely used laboratory hardware. The battery is intended for use with neurologically impaired and other naïve subjects, to allow inference at the single-subject level for any given subtest. The aim is to allow a systematic psychoacoustic evaluation of complex sound processing in single patients. Normal values are given for the threshold data for 30 naïve control subjects aged from 20 to 60 years. Future modifications of the battery are allowed by modular software architecture. 

*Key words:* Human; Psychophysics; Lesion; Test battery

## 1. Introduction

We have carried out a number of studies to investigate the perception of complex sound showing temporal or spatial variation (Griffiths et al., 1997a,b, 1998b). These studies were carried out on neurological patients with central lesions and no experience of psychophysical testing. In these studies we have used a cognitive neuropsychological approach (Ellis and Young, 1988) to define *dissociated* deficits in certain auditory functions. From a purely psychophysical perspective, this allows inference about the existence of discrete psychophysical mechanisms for the perception of certain types of complex sound. Additionally, comparison of such deficits with the known anatomical lesion allows inference about the likely neural substrate for the perceptual process. This approach is based upon certain requirements. Firstly, abnormality for any given subject, and any given subtest, must be defined with appropriate statistical confidence. This distinguishes our approach from the use of population-based inference for *groups* with homogeneous lesions (e.g. Zatorre, 1988). Secondly, normality must be defined with respect to an appropriate control group. Such a control group consists of *naïve* subjects of *similar age*, carrying out the same task under similar conditions; data accrued from more prolonged studies of trained paid volunteers or young undergraduates are not adequate for this purpose.

Here we present a battery of tests of spatial and temporal auditory processing for use with neurological patients (the Newcastle Auditory Battery, NAB). This battery allows normality or abnormality to be defined for each test, for each subject tested, using two-alternative-forced-choice (2AFC) psychophysics. We report our initial control data based on 30 naïve normal subjects.

We also describe a personal computer software platform to carry out these tests (also called the Newcastle Auditory Battery, NAB). This has the following features. The software is implemented within a commercially available package (Matlab™, The Mathworks, Inc., USA). It is implemented on a personal computer that can be coupled to commercially available TDT hardware for sound delivery (® Tucker Davis Technol-

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ogies, California, USA), or it can use an internal sound card for greater portability. The software is modular, allowing the user to employ only specific subtests, or add additional tests as required. This communication describes the practical procedure for any reader to obtain this software.

We anticipate that this battery might also be of use to workers investigating temporal or spatial auditory abnormalities in cognitive groups without well-defined lesions, such as developmental dyslexics (Witton et al., 1998).

## 2. Psychophysical details and normal data for the NAB

The tasks are all 2AFC tasks carried out binaurally over headphones, at a sensation level of 60 dB, unless stated otherwise. The sensation level for the TDT system is relative to the measured noise or tone threshold. Using our headphones in a sound-proofed room the pure tone thresholds correspond to a hearing level according to ISO 389. For the sound card version the sound level needs to be calibrated using a sound level meter and we encourage users to obtain separate audiograms. For all tasks, subjects are given a period of several minutes of practice with feedback using a single suprathreshold level for the sound parameter under test. The default level based on our normal control data can be adjusted if the threshold appears high, before carrying out the full psychometric function. For any experimental run, six levels are used for each task, and 10 trials acquired at each level in a random order. The temporal and spatial batteries can be carried out in a period of 2–3 h each, and most subjects can comfortably complete the whole battery in two separate sessions of this length. The data yielded by running the battery using TDT hardware in a soundproof room or using the laptop version in a quiet room do not show significant differences in a cross-validation study (Appendix 2).

The tasks were carried out by 30 naïve control listeners (15 in age range 20–39, 15 in age range 40–59; see Appendix 1 for further demographics). A full psychometric function was plotted for each subtest for each control subject. In this study the threshold was derived from a Weibull function fitted using an automated algorithm but the package does not constrain the user to employ any particular function or algorithm. The 75% threshold value was calculated from this function. The standard deviations for the data are given to allow users to derive appropriate confidence intervals. For some of the subtests a log transformation of the data was necessary to achieve a normal distribution; for these tests the mean and standard deviation of the log-transformed data are reported.

### 2.1. Temporal test battery

The temporal test battery includes tests of the detection of frequency- and amplitude-modulated sound at different modulation rates (T1–T6). These rates correspond to different points in the modulation transfer function (Zwicker, 1952; Kay, 1982) and allow examination of different types of temporal processing. The latter term is often used without precision as if temporal processing were a unitary process, and one of the main motivations for the development of this battery is to allow the systematic examination of different temporal processes in brain disorders (see Griffiths, in press, for discussion). The low modulation rate used (2 Hz) corresponds to a temporal window at the level of hundreds of milliseconds that may be relevant to the processing of music and prosody. The higher rates (40 Hz and 120 Hz) correspond to temporal windows at the level of milliseconds or tens of milliseconds, relevant to the fine structure of speech and other sounds. Psychophysical (Zwicker, 1952; Kay, 1982) and imaging work (Harms et al., 1998) on normal human subjects, and animal neurophysiological work (Møller, 1974; Rees and Møller, 1983) all suggest that the processing of sound modulated at different rates has different psychophysical and anatomical bases.

The threshold for the detection of binaural sinusoidal frequency modulation is measured at three rates, 2 Hz (test T1), 40 Hz (test T2) and 120 Hz (test T3). The carrier frequency is 500 Hz and duration of each sound 1 s. Table 1 gives the threshold for each task. Modulation index for frequency-modulated (FM) sound corresponds to the ratio of the frequency excursion to the modulation rate. The threshold for the detection of binaural sinusoidal amplitude modulation is measured at three rates, 2 Hz (test T4), 40 Hz (test T5) and 120 Hz (test T6). The carrier frequency and duration are the same as for the FM tasks. Table 1 gives the threshold at each level as modulation index. Modulation index for amplitude-modulated (AM) sound corresponds to the proportional depth of modulation.

Test T7 measures gap detection threshold, which is a temporal property of discrete rather than continuous sound as in the modulation tests. Subjects are required to detect a temporal gap between a 10-ms leading marker and a 300-ms trailing marker. A sensation level of 35 dB is used. The procedure uses two 'within channel' tasks based on Gaussian noise at different centre frequencies. These tasks serve as controls for the 'between channel' task which is employed as a 'central' timing task (Phillips et al., 1997). Table 1 gives the threshold for each task.

Test T8 measures threshold for the detection of iterated rippled noise (IRN, Patterson et al., 1996). In the broadest terms this is a complex pitch task. The stimulus is perceived as a noise with a pitch, with perceptual properties more parsimoniously explained on the basis of the fine time structure of the stimulus, or temporal microstructure (Griffiths et al., 1998a). The test is included as a test of such temporal processing at a finer level than that employed in the modulation and gap detection tasks. Bandpass noise with passband 1–4 kHz is used, and a delay of 10 ms. The target interval contains IRN with eight iterations and gain varied between 0.01 and 0.32 in octave steps. The control interval contains noise only. The threshold gain for the detection of IRN is given in Table 1.

### 2.2. Spatial test battery

The spatial battery assesses the detection of simple interaural time and intensity cues presented over headphones. This is intended as a first stage in the evaluation of spatial sound processing disorders and uses stimuli that are parallel to those used in the temporal battery (for example, T1, the detection of 2 Hz FM, is a control task for S3, the detection of 2 Hz interaural phase modulation).

Table 2 gives the thresholds for the spatial tasks. Fixed spatial difference limens are measured for the detection of the lateralisation of a centred 500-Hz tone toward the right or left. S1 measures the phase difference limen and S2 the amplitude difference limen. In S1 the phase of the tone is advanced in one ear and retarded in the other; the threshold is expressed as the phase excursion in radians. In S2 the amplitude is increased in one ear and decreased in the other; the threshold is expressed as the proportional change in amplitude. *Dynamic* lateralisation is measured in tests S3 and S4. In these tasks, the phase or amplitude of a 500-Hz tone is sinusoidally advanced at one ear and retarded at the other which produces the percept of sinusoidal movement of a single source between the ears. S3 measures interaural phase modulation and S4 interaural amplitude modulation. The thresholds as modulation index are given in Table 2. The corresponding control stimuli with matched waveforms at the two ears (Green et al., 1976; Griffiths et al., 1996) are binaural frequency modulation (T1) and binaural amplitude modulation (T4). The mean threshold for the dynamic phase task (S3) is significantly smaller ($P < 0.05$ for separate $t$-tests on older and younger age cohorts) than the control frequency modulation task (T1), as demonstrated in previous work (Griffiths et al., 1996). The thresholds for the detection of interaural phase modulation are lower by a factor of 6.6 (age group 20–39) and 4.8 (age group 40–59). For the amplitude tasks the mean thresholds are not significantly different in either age group.

Tests S5 and S6 measure the thresholds for the detection of a 600-ms phase or amplitude ramp to the right or left. In these tasks, the phase or amplitude of a 500-Hz tone is linearly advanced at one ear and retarded at the other, which produces the percept of linear movement of a single source from the midline toward one side. The threshold for each task is given in Table 2. The units for the phase and amplitude excursions are radians and proportional amplitude change respectively, as in S1 and S2.

## 3. Use of the normal data

*Every* subtest in the temporal and spatial batteries shows a greater threshold for the older age cohort,

Table 1
Threshold data for naïve subjects: temporal subtests

| Task | Threshold | |
|---|---|---|
| | Age group 20–39 | Age group 40–59 |
| T1, 2 Hz FM | −0.155 (0.185) (LOG) | 0.0136 (0.183) (LOG) |
| T2, 40 Hz FM | −1.35 (0.184) (LOG) | −1.22 (0.160) (LOG) |
| T3, 120 Hz FM | 0.0120 (0.00635) | 0.0161 (0.00758) |
| T4, 2 Hz AM | −1.36 (0.265) (LOG) | −1.02 (0.264) (LOG) |
| T5, 40 Hz AM | −1.41 (0.179) (LOG) | −1.30 (0.136) (LOG) |
| T6, 120 Hz AM | −1.98 (0.270) (LOG) | −1.85 (0.249) (LOG) |
| T7a, Within high channel gap detection (ms)* | 0.652 (0.382) (LOG) | 1.04 (0.240) (LOG) |
| T7b, Within low channel gap detection (ms)* | 0.912 (0.343) (LOG) | 1.11 (0.242) (LOG) |
| T7c, Between channels gap detection (ms)* | 1.39 (0.393) (LOG) | 1.70 (0.348) (LOG) |
| T8, IRN (gain)* | −1.15 (0.117) (LOG) | −1.05 (0.176) (LOG) |

All data are expressed as threshold modulation index, unless otherwise specified. The thresholds are all based on six levels for each subject and 20 trials per level except those marked with an asterisk, based on 10 trials per level. The mean threshold and standard deviation are quoted for two age ranges, 20–39 ($n = 15$) and 40–59 ($n = 15$). The subtest values shown as LOG correspond to subtests for which a log transformation of the data was necessary to achieve a normal distribution. In such cases the mean and standard deviation of the log-transformed data are reported. To find the appropriate confidence limits in such cases limits based on the appropriate multiple of the standard deviation of the log-transformed data need to be used and transformed.

although this is only significant at the $P < 0.05$ level for the phase ramp task (S5), and that result would not withstand Bonferroni correction for multiple comparisons. This cautions against the use of inappropriate control data (without age matching) in making inference about normality or abnormality in any given patient. The other feature of the data is the broad confidence interval for all of the subtests. This cautions against the use of single subjects as controls rather than control groups. We encourage any users of this battery to regard the values we report as an initial guide and to obtain their own control data for a group of subjects, with appropriate matching for age and other demographic measures.

## 4. Implementation of the NAB

### 4.1. Software details

The code is available as a compressed file in pc .zip format (filename = NAB2001) and can be obtained from http://www.brain.ncl.ac.uk/NAB. The software calls C routines from Matlab5 (© The Mathworks) using .mex functions. The code should be installed into a Matlab subdirectory and the paths specified accordingly. No compiler is required. The file NAB.html in the same directory describes in detail the use of the battery.

### 4.2. System requirements/execution

The decompressed code occupies 5.12 Mbytes. Apart from a personal computer with a processing speed of 200 MHz or above, the system requires either an accompanying TDT system (see Appendix 3 for specification used in this design) or a high-specification sound card. The system has been developed using an AWE 64 Gold device (Creative Technology Ltd.) and will run on similar specification cards. The software will detect a TDT array processor card if present and allow the user to specify whether sound card or TDT usage is required. The sample rate is 44 100 for both the sound card and TDT versions.

The TDT version measures pure tone and noise thresholds using the programmable attenuators available as part of that system; these values are used to set sensation levels for the other tasks. The absolute thresholds for pure tones measured with the TDT system have been calibrated against audiometric standards using Sennheiser HD 25SP headphones. The default settings should not be relied upon for audiometry without recalibration. However, threshold determination using the software is required for setting sensation levels for the other tests. For the sound card system the sensation levels for the temporal and spatial tests have to be set using the system intensity control and a sound level meter.

Subject responses are recorded via a button box (TDT version) or mouse response (sound card version) and a running psychometric function is displayed in a window to allow the researcher to abort and adjust parameters early in the test if necessary. The data are saved to a separate Matlab .mat file and text file suitable for use with graphical/statistical packages.

## 5. Summary

A battery of temporal and spatial tasks is described here suitable for the psychoacoustic evaluation of neurologically impaired and other naïve subjects. Two versions are described, one that could be used with a portable personal computer and sound card. The battery is designed as an initial battery of tasks of temporal and spatial processing, which can be completed by most subjects in approximately 5 h. Inference about the performance of individual tasks in individual subjects is permitted by measuring full psychometric functions using 2AFC and comparing the data with normal values. This is not intended to be a complete battery of temporal and spatial tasks. In the temporal battery we have not included tasks of the perception of sequences of

Table 2
Threshold data for naïve subjects: spatial subtests

| Task | Threshold | |
|---|---|---|
| | Age group 20–39 | Age group 40–59 |
| S1, Phase difference limen | −1.21 (0.321) (LOG) | −1.09 (0.323) (LOG) |
| S2, Amplitude difference limen | −0.951 (0.246) (LOG) | −0.838 (0.248) (LOG) |
| S3, 2 Hz interaural phase modulation | −1.03 (0.242) (LOG) | −0.751 (0.302) (LOG) |
| S4, 2 Hz interaural amplitude modulation | −1.17 (0.240) (LOG) | −0.952 (0.190) (LOG) |
| S5, Phase ramp | −0.792 (0.342) (LOG) | −0.566 (0.190) (LOG) |
| S6, Amplitude ramp | 0.195 (0.160) | 0.267 (0.108) |

All thresholds expressed as dimensionless units: S1 and S5 as radians, S2 and S6 as proportional amplitude change and S3 and S4 as modulation index. The threshold data for S1, S2, S3 and S4 are based on the combined data for trials to the left and right (10 trials per level for each direction). Log transformations are used where appropriate as in Table 1.

segmented sounds, or backward masking. In the spatial battery we have only included headphone tests of static and dynamic lateralisation: we have not included any tests of the perception of real or virtual acoustic space. Further tasks could be included in the future as further modules to supplement this core battery.

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## Appendix 1. Subject characteristics

Hand dominance was assessed using a shortened version of the (Annett, 1970) hand dominance questionnaire (Right means a score of 6/6 for right hand dominance). Each subject completed a detailed questionnaire about hearing symptoms and no subject had a history to suggest any otological disorder. Two subjects were rejected from the study due to a history of occupational noise exposure or iatrogenic hearing loss.

| | Age group 20–39 years | | Age group 40–59 years | |
|---|---|---|---|---|
| | Male | Female | Male | Female |
| *n* | 7 | 8 | 7 | 8 |
| Mean age | 21.9 | 28.6 | 49.7 | 49.5 |
| Age range | 20–25 | 21–39 | 43–58 | 43–58 |
| Hand dominance | All Right | All Right | All Right | All Right |

## Appendix 2

Threshold data for cross-validation of the temporal and spatial subtests. The full battery was carried out on four subjects (all female, aged 22–24) using both the TDT battery in a sound-proofed room and the sound card version in a quiet room. Paired *t*-test did not demonstrate any significant differences between the thresholds for any subtest at the $P < 0.05$ level.

## Appendix 3

The software has been used with the following TDT hardware components: power supply, X buses, AP2 card, digital to analogue conversion using PD1 or DA3-4, FT6 filters, PA4 attenuators, WG1 waveform generator, PI2 interface with button box response, HB6 headphone buffer, SM3 summer. See http://www.brain.ncl.ac.uk/NAB for TDT hardware configuration.

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