

# Prevalence of Central Auditory Processing (CAP) Abnormality in an Older Australian Population: The Blue Mountains Hearing Study

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## Abstract

Age-related central auditory processing (CAP) abnormality has been described in many studies with widely varying prevalence reported. To date, there has been only one population study to report prevalence for this age-related condition, and these rates were significantly lower than in reports from clinical studies. The present study reports findings from a recent population study in which 2,015 Australians aged 55 years and older living in a defined area west of Sydney were assessed with a battery of behavioral and electrophysiological auditory tests. This battery included speech measures from which a high overall prevalence rate (76.4%) of CAP abnormalities was found, in keeping with previous clinical studies. While gender differences were dependent on the test measure, the number of abnormal test outcomes increased systematically with age. Hearing loss and abnormal cognitive function, however, did not systematically increase with number of abnormal test outcomes.

**Key Words:** Aging, central auditory disorder, hearing loss, prevalence

**Abbreviations:** AB = Arthur Boothroyd monosyllabic word list materials; BMES = Blue Mountains Eye Study; BMHS = Blue Mountains Hearing Study; CAP = central auditory processing; CID W-22 = Central Institute for the Deaf W-22 word lists; DSI = Dichotic Sentence Identification test; MDSI = Macquarie Dichotic Sentence Identification test; MMSE = Mini Mental State Exam; MSSI = Macquarie Synthetic Sentence Identification test; MSSI:ICM = Macquarie Synthetic Sentence Identification test with Ipsilateral Competing Message; MSSImax = maximum performance score on the Macquarie Synthetic Sentence Identification test; PBmax = maximum performance score on the monosyllabic word list materials; PTA = average of air-conducted pure-tone thresholds for 500, 1000, and 2000 Hz; SSI = Synthetic Sentence Identification test; SSI:ICM = Synthetic Sentence Identification test with Ipsilateral Competing Message; SSIImax = maximum performance score on the Synthetic Sentence Identification test

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## Sumario

Las anomalías en el procesamiento auditivo central (CAP) relacionadas con la edad han sido descritas en muchos estudios, y también se reporta una prevalencia muy variable. A la fecha, sólo ha existido un estudio poblacional que reporte la prevalencia de esta condición relacionada con la edad, y dichas tasas fueron significativamente más bajas que aquellas reportadas en estudios clínicos. El presente estudio reporta los hallazgos de un estudio reciente de población en el que 2015 australianos, con edad por encima de los 56 años y viviendo en un área definida al oeste de Sydney, fueron evaluados con una batería de pruebas auditivas de tipo conductual y electrofisiológico. Esta batería incluyó mediciones logaudiométricas en las que se encontró una alta tasa global de prevalencia (78.4%) de anomalías en el CAP, al igual que en estudios clínicos previos. Aunque las diferencias de género dependieron de la medida evaluada, el número de resultados anormales de las pruebas se incrementó sistemáticamente con la edad. La pérdida auditiva y la función cognitiva anormal, sin embargo, no se incrementaron sistemáticamente con el número de resultados anormales en dichas pruebas.

**Palabras Clave:** Envejecimiento, trastorno auditivo central, pérdida auditiva, prevalencia

**Abreviaturas:** AB = Lista de palabras monosilábicas de Arthur Boothroyd; BMES = Estudio Ocular de Blue Mountains; BMHS = Estudio Auditivo de Blue Mountains; CAP = procesamiento auditivo central; CID-W22 = Listas de palabras W22 del Instituto Central del Sordo; DSI = Prueba de identificación de frases dicóticas; MDSI = Prueba de identificación de frases dicóticas de Macquarie; MMSE = Mini-examen de estado mental; MSSI = Prueba de identificación de frases sintéticas de Macquarie; MSSI-ICM = Prueba de identificación de frases sintéticas de Macquarie con mensaje competitivo ipsilateral; MSSImax = Puntaje máximo de desempeño en la prueba de identificación de frases sintéticas de Macquarie; PBmax = Puntaje máximo de desempeño con listas de palabras monosilábicas; PTA = promedio de umbrales tonales por vía aérea a 500, 1000 y 2000 Hz; SSI = Prueba de identificación de frases sintéticas; SSI-ICM = Prueba de identificación de frases sintéticas con mensaje competitivo ipsilateral; SSIImax = Puntaje máximo de desempeño en la prueba de identificación de frases sintéticas

**T**he prevalence of central auditory processing (CAP) abnormality in older adults has been debated for many years. Clinical studies have suggested that well over 50% of older persons exhibit CAP abnormality and that this figure continues to rise with age (Shiranian and Arnst, 1982; Jerger et al, 1989; Rodriguez et al, 1990; Stach et al, 1990). In contrast, Cooper and Gates (1991) reported findings from the longitudinal study of an older population known as the Framingham cohort, in which 1,026 persons aged 64–93 years were assessed and the reported prevalence of CAP abnormalities was far less at 22.6%. Such information, from population-based studies where prevalence rates are established, is a

critical preliminary to decisions regarding the ongoing funding of research into the treatment or rehabilitation of the condition.

Gender and laterality differences with age have also been examined using speech measures of auditory processing, but outcomes have varied. Some studies have reported that gender differences do exist (Shiranian and Arnst, 1982; Jerger et al, 1994; Dubno et al, 1997) while others report that no difference exists (Stach et al, 1990; Cooper and Gates, 1991). Laterality effects have also differed across studies with higher rates of right than left ear abnormality reported in one study (Shiranian and Arnst, 1982), increasing left ear deficit with age noted in another (Jerger et al, 1994) and age-

dependent changing laterality effects reported in a third study (Stach et al, 1990). This variability may have resulted from the differing subject exclusion criteria, test protocols, and the choice of assessment tools used across studies.

As there has been only one population-based study of CAP abnormality in the older age group that reports prevalence, and significantly, it reported lower prevalence than that reported from clinical studies, it now seems appropriate to add to this discussion by reporting findings from a recent population-based study of older Australians, the Blue Mountains Hearing Study (BMHS). The purpose of the present study was to calculate age-specific prevalence rates for CAP abnormality as related to specific speech-based measures. This condition was defined in the typical manner (i.e., the overall prevalence rate reflects abnormality on any one test outcome) and also using a grading system based on the number of abnormal test outcomes where the minimum prevalence equals abnormality on all test outcomes. Results are examined by gender and by ear. The test results are also examined in the light of hearing loss given the potential influence of this factor on the test outcomes (Jerger et al, 1990; Divenyi and Haupt, 1997; Dubno et al, 1997; Bamioiu et al, 2000).

## METHODS

### Subjects

The BMHS, conducted during 1997–99, is a population-based survey of age-related hearing loss in a representative older Australian urban community (Sindhusake et al, 2001). Participants are members of the larger Blue Mountains Eye Study (BMES), which is a longitudinal study of eye and health-related changes in an older population. Findings from the first BMES (known as BMES-1) have been widely reported in the literature since 1996 (Attebo et al, 1996; Mitchell et al, 1997; Mitchell et al, 1998; Wang et al, 2000). The BMHS, conducted in conjunction with the five-year follow-up examinations of the BMES (known as BMES-2), examined 2,015 people aged 54–99 years (mean age = 69.84 yrs., SD = 8.56). This represented 74.7% of all people aged 55 years and over who were permanent residents,

during the study period, of two postal code districts of the Blue Mountains, west of Sydney. There were 859 male participants (mean age = 69.73 yrs., SD = 8.34) and 1,156 female participants (mean age = 69.92 yrs., SD = 8.67), and 98% were Caucasian while 60.9% had completed technical training after their high school diploma year or had higher education qualifications.

For the purposes of this study, participants were excluded from undertaking the speech-based measures if they were unable to fluently read the sentences appearing on the test cards. They were also excluded if their pure-tone average (PTA) for 500, 1000, and 2000 Hz was greater than 50 dB HL in either ear, and/or there was a PTA asymmetry of greater than 30 dB HL. This was necessary so that poor performance on the core speech measures was not misinterpreted. The speech measures reported in this study are designed for presentation at suprathreshold levels, in order to achieve a participant's best performance. Without adequate audibility or in the presence of potential cochlear distortion, the interpretation of results is obscured. The exclusion criteria applied in this study were based on earlier reports, in which the lower limit of performance for subjects with moderate peripheral hearing loss has been demonstrated for the maximum performance score on the Synthetic Sentence Identification test (SSImax) and the Dichotic Sentence Identification test (DSI) (Fifer et al, 1983; Yellin et al, 1989). With increasing severity of loss, the ability to distinguish between CAP abnormality and that arising from peripheral loss becomes difficult.

Of the 2,015 BMHS participants, 439 were excluded, the greatest number by the application of this hearing loss criteria (N = 216) and the rest for the following reasons: poor eyesight or written/spoken language difficulties (N = 55); incomplete assessments (N = 56); frailty (N = 31); inadequate test time (N = 25); because the subjects were not tested with speech measures for unspecified reasons (N = 44); and because no hearing thresholds were obtained, therefore negating calculation of speech presentation levels (N = 12). Thus, 1,576 participants were able to complete the test battery reported in this study.

When asked to rate their overall general health, 82.1% of these participants reported good or excellent health for their age with only

**Table 1. The Mean of the Pure-Tone Average for All Subjects (N = 1576) and 95% CI for Right and Left Ears as a Function of Age Groups**

Age group	N	Right ear Mean (95% CI)	Left ear Mean (95% CI)
≤ 64 years	532	12.18 (11.51 to 12.84)	13.12 (12.42 to 13.81)
65–74 years	689	18.23 (17.46 to 19.01)	19.23 (19.49 to 19.97)
75+ years	355	22.68 (21.6 to 23.76)	23.99 (22.87 to 25.12)

2.1% rating their health as poor. BMES-2 examiners rated 98.9% of participants as free of obvious language impairments based on interactive conversation with the examiner during the interview, and less than 1% as suffering from impaired speech.

The participants were divided into three age groups for descriptive purposes: ≤64 years (N = 532), 65–74 years (N = 689), 75+ (N = 355) years. Table 1 shows the mean PTA and 95% CI for right and left ears, for each age group. Only 14 dB HL separated the 95% CI lower boundary of the youngest age group (better ear) and the 95% CI upper boundary of the oldest age group (poorest ear), and the mean PTA was better than 25 dB HL in both ears for all age groups.

### Procedures

The BMHS consisted of an extensive questionnaire and a battery of behavioral and physiologic auditory measures including pure-tone audiometry and the speech recognition measures reported in this study. The demographic information and health-related questionnaires included a cognitive screening test, the Mini Mental State Exam (MMSE), which was administered by trained examiners as part of the BMES-2 examinations. The MMSE (Folstein et al, 1975) measures a variety of cognitive functions and was selected for the BMES as it is short, easy to administer and has reasonable sensitivity and specificity (Tombaugh and McIntyre, 1992). Its suitability to population studies as a screening tool of cognitive function has been previously described (Bachman et al, 1992).

Testing related to the audiologic measures was conducted in sound-treated facilities by experienced masters-level audiologists using Madsen two-channel audiometers calibrated to Australian Standards (ISO: 389,1991) and Technics CD players. Pure-tone audiometry was performed on all 1,576 participants and consisted of air-conduction thresholds for 250,

500, 1000, 2000, 4000, 6000, and 8000 Hz in both ears. Bone-conducted thresholds with masking applied when appropriate were established for 500, 1000, 2000, and 4000 Hz whenever air-conducted thresholds were above 15 dB HL. Speech recognition measures included the Arthur Boothroyd (AB) Monosyllabic Word Lists recording from the National Acoustic Laboratories (Travers, 1990), which is scored phonemically and is widely used in Australian clinics. The newly developed Australian versions of the original Synthetic Sentence Identification (SSI) test and the Dichotic Sentence Identification (DSI) test, known as the Macquarie Synthetic Sentence Identification (MSSI) test and the Macquarie Dichotic Sentence Identification (MDSI) test, formed the core elements of the speech battery. The MSSI test and the MDSI test utilize the same test sentences as in the original SSI and DSI tests but were re-recorded using a male speaker of general Australian, and the continuous discourse (competing message) of the MSSI test recounts the natural history of an Australian marsupial rather than the American legend of Davy Crockett. The performance characteristics of the MSSI and MDSI are similar to that achieved using the original tests in normal adult populations (Golding, 2001).

A wide variety of CAP measures suited to the assessment of adult populations exist. Tests with high linguistic redundancy were chosen for this study as they are meaningful stimuli and therefore likely to be appealing to the older population, and they are also relatively tolerant of moderate hearing loss. The original SSI test in its ipsilateral competing message format (SSI:ICM at 0 message-to-competition ratio) is thought to reflect activity primarily at the level of the brainstem (Jerger and Jerger, 1975; Musiek, 1983) and has been used in both clinical and population studies. This test, however, is not directly applicable to Australian use, but the MSSI test emulates the original and thus permits the opportunity for a comparative

review of our results and those from previous studies. The DSI is thought to primarily reflect activity at a more cortical level (Bamiou et al, 2000) and therefore provides a complementary measure without a complete change of task, thus keeping test time to a minimum. As the central auditory pathway is complex and changes may presumably occur anywhere along its length, two measures that generally target different parts should improve the detection of CAP abnormalities.

The Macquarie Synthetic Sentence Identification test with an ipsilateral competing message (MSSI:ICM) format was presented at several intensities using the typical 0 dB message-to-competition ratio. The test presentation levels were equal to the PTA of the test ear plus 30 dB SL, 50 dB SL, and, in some cases, plus 10 dB SL. Previous reports indicated that when multiple test presentation levels were delivered the SSI maximum performance score (SSImax) could be estimated and should be achieved with PTA +30 dB HL (Jerger et al, 1968), but the maximum performance score for the MSSI (MSSImax) test appears to be achieved at a higher level of PTA +50 dB HL (Golding, 2001). The AB Monosyllabic Word Lists were similarly delivered at several presentation levels with a maximum performance score (PBmax) expected at PTA +50 dB SL in an older population (Gang, 1976). The MDSI was delivered with a sensation level of 20 dB relative to the PTA of the poorer ear, which followed procedural recommendations for the original DSI test (Chmiel and Jerger, 1996).

Participants were instructed in the tasks following standard procedures outlined previously (Golding, 2001). In the case of the MSSI test, they were asked to completely ignore the ongoing story and to identify and state the number of the sentence heard. For the MDSI test, their task was to listen to and report both sentences (presented simultaneously to right and left ears) by numbers only and with no particular regard to order. All possible sentences were written in large print on test cards and presented to the participant at the start of each exercise. Practice lists, using an SNR of +10 for the MSSI:ICM test and the recommended test presentation level for the MDSI test, preceded each test during which the participant's competency at the tasks was checked. All participants acknowledged that they were able to see and read the test cards,

understood the task, and demonstrated their ability to perform the task by correctly identifying at least some of the practice items. They were not excluded from participation for missing some items as this would bias the outcome in favor of high performances. The final test results were converted to the percent correct for both tests and for both ears. The MSSI:ICM test was delivered before the MDSI test but after pure-tone audiometry, while the AB Monosyllabic Word Lists were generally presented last.

### CAP Abnormality Criteria

The interpretation of results arising from the SSI and DSI tests has been well documented (Fifer et al, 1983; Hannley et al, 1983; Jerger et al, 1989; Yellin et al, 1989). As the MSSI and MDSI emulate the performance characteristics of these tests, participants in this study were categorized as showing evidence of CAP abnormality using the same criteria as follows:

1. If the PBmax-MSSImax score was >20% in the right ear or in the left ear (Hannley et al, 1983).
2. If the MSSImax ear score for the right ear or for the left ear was poorer than expected given the previously reported performance scores for normal hearers and cochlear hearing loss (Yellin et al, 1989).
3. If the MDSI ear score for the right ear or for the left ear was poorer than expected given the previously reported performance scores for normal hearers and cochlear hearing loss (Fifer et al, 1983; Jerger et al, 1989).
4. If the difference between ears on the MDSI test is greater than expected given the previously reported performance scores when hearing loss is evident and asymmetric (Fifer et al, 1983; Jerger et al, 1989; Chmiel and Jerger, 1996).

While evidence of "rollover" where the performance score declines for presentation levels above that which achieved maximum has been reported as evidence of CAP abnormality, interpretation of this phenomenon in the older population has been questioned at least for monosyllabic word list materials (Jerger and Jerger, 1971; Gang, 1976). In the present study, time did not permit testing at the high-intensity levels necessary to establish the existence of "rollover," so it was not included as a criterion.

**Table 2. The Proportion (reported as a %) and Number of Participants with Abnormal Test Outcomes on One or More Tests**

Number of abnormal tests	N	% participants	Cumulative %
One	188	11.9	11.9
Two	274	17.4	29.3
Three	194	12.3	41.6
Four	205	13.0	54.6
Five	125	7.9	62.5
Six	187	11.9	74.4
Seven	31	2.0	76.4

Thus, the seven test outcomes outlined above, that is, PBmax-MSSImax for right and for left ears, MSSImax ear score for right and for left ears, MDSI ear score for right and for left ears, and the MDSI difference score, represent the criteria used to estimate prevalence in this study.

### RESULTS

The statistical independence of the seven test outcomes was confirmed using a correlation matrix. The Pearson correlation ( $r$ ) ranged from 0.152 to 0.680, and all were significant ( $p < .001$ ), but multicollinearity was not evident.

Table 2 shows the proportion of participants with abnormal test outcomes by the number of abnormal tests. The minimum prevalence of CAP abnormality defined as abnormality on all seven test outcomes was 2%, while the overall prevalence rate of CAP abnormality defined as abnormality on one or more of the seven test outcomes was 76.4% ( $N = 1204$ ). An independent samples  $t$ -test (equal variance not assumed) showed that the mean age of participants with seven normal test outcomes was significantly less than the mean age of

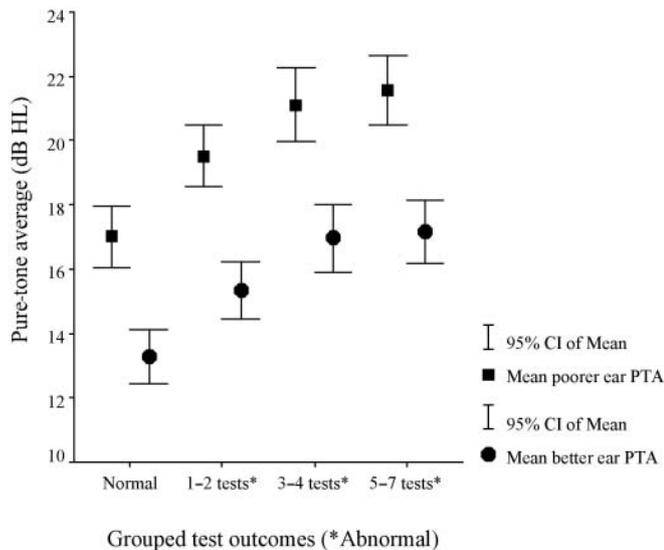
participants (i.e., 23.6% of the participants) with one or more abnormal test outcomes ( $t[709.23] = -11.62$ ;  $p < .001$ ). For the purposes of this study, the seven test outcomes were also grouped four ways: those with all normal test outcomes, one to two abnormal test outcomes, three to four abnormal test outcomes, and five to seven abnormal test outcomes.

Table 3 shows these grouped test outcomes as a function of the age of participants; the three groups were  $\leq 64$  years, 65–74 years, and 75+ years. With increasing age, there were proportionally more participants with an increasing number of abnormal test outcomes, for example, 9.0% of the youngest group had five to seven test outcome abnormalities while 39.9% of the oldest group had five to seven test outcome abnormalities. The mean age for each grouped test outcome was calculated. An ANOVA on the mean age difference indicated a highly significant difference in age between the four groups ( $F[3,1572] = 84.09$ ,  $p < .001$ ). Tukey's HSD showed that the mean age for each group differed significantly from the remainder ( $p < .001$ ).

Figure 1 shows the grouped test outcomes as a function of the mean PTA and 95% CI for the better and poorer ear. A range of only 10

**Table 3. The Proportion (reported as a %) and Number of Participants in Each Age Group by Grouped Test Outcomes**

Grouped Test Outcomes	N	Age groups in years (N)		
		$\leq 64$ (532)	65–74 (689)	75+ (355)
Normal	372	35.8	21.8	9.1
One to two abnormal	462	33.6	29.9	21.7
Three to four abnormal	399	21.6	26.2	29.3
Five to seven abnormal	343	9.0	22.1	39.9



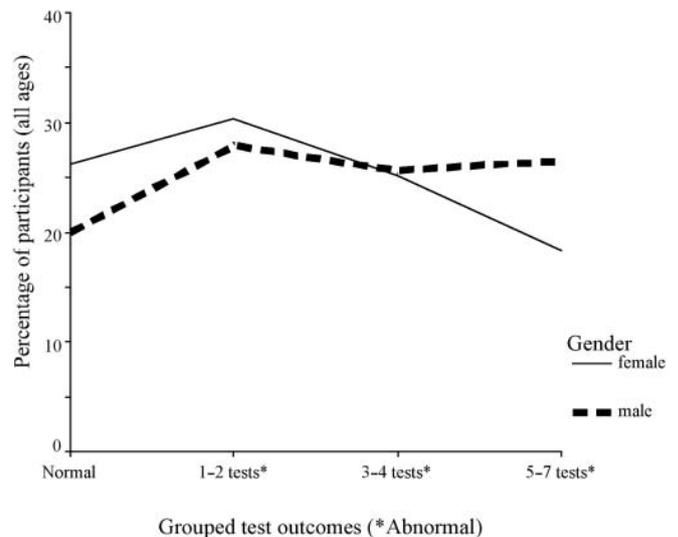
**Figure 1.** Grouped test outcomes as a function of the mean pure-tone average for the poorer ear and the better ear. The 95% CI of the means are indicated and show significant overlap when three or more abnormal test outcomes are present.

dB HL is observed from the better ear normal test outcome group to the poorer ear five to seven abnormal test outcomes group. The mean PTA was, however, significantly different across the grouped test outcomes in both cases (poorer ear:  $F[3,1572] = 14.36$ ,  $p < .001$ , better ear:  $F[3,1572] = 12.86$ ,  $p < 0.001$ ), but Tukey's HSD showed that the relationship of increasing hearing loss with increased test abnormality reached a plateau beyond the point of three test outcome abnormalities.

The MMSE results were highly skewed with only 1.4% of participants failing with a score less than 24 out of 30. When the scores are examined by grouped test outcomes, a normal score with a mean value  $\geq 27$  out of 30 (SD 1.04–2.1) was found for all groups.

Figure 2 shows grouped test outcomes for men and women. There is a gender effect although the association is relatively weak ( $\chi^2 = 18.86$ ,  $p < .01$ ; Cramer's  $V = 0.11$ ,  $p < 0.001$ ). While 73.8% ( $N = 676$ ) of women and 80% of men ( $N = 528$ ) showed abnormality on one or more test outcomes, proportionally, women had 30% lower odds than men to show abnormal outcomes. (Odds ratio 0.7, CI [0.55–0.89] [ $\chi^2 = 8.18$ ,  $p = .004$ ]).

Table 4 shows that the proportion of participants with binaural abnormalities increases with age. While 12% ( $N = 189$ ) of participants showed right ear only



**Figure 2.** Grouped test outcomes by gender where women are proportionally more likely to have normal test results and men are more likely to have a higher number of abnormal test outcomes.

abnormalities and 20.3% ( $N = 320$ ) showed left ear only abnormalities, 44.1% ( $N = 695$ ) showed binaural abnormalities. The mean age for each of the abnormal test outcomes by ear grouping was calculated. An ANOVA on the mean age difference indicated that a significant difference in age between these three groups exists ( $F[2,1201] = 51.27$ ,  $p < .001$ ). Tukey's HSD, however, showed that this significant difference was between the binaural abnormal test outcome group and the unilateral groups only ( $p < .001$ ). There was no significant difference in age between the right ear only and left ear only abnormal test outcomes ( $p = 1.0$ ).

## DISCUSSION

This study indicates a high overall prevalence of CAP abnormality (76.4%) with age and a minimum prevalence of 2.0%. High overall prevalence rates have been reported in all previous studies except the Framingham cohort study. While test measures were not identical between studies, the PBmax-SSImax has commonly been used. Indeed the Framingham study used this tool while our study used the equivalent PBmax-MSSImax. The Framingham study reported a prevalence rate of 18.1% using the single measure of PBmax-SSImax (Cooper and

**Table 4. The Proportion (reported as a %) and Number of Participants in Each Age Group by Ear Outcomes**

Test outcomes by ear	N	Age groups in years (N)		
		≤64 (532)	65–74 (689)	75+ (355)
Normal both ears	372	35.7	21.8	9.0
Right ear only abnormal	189	13.5	13.1	7.6
Left ear only abnormal	320	23.5	20.9	14.4
Binaural abnormality	695	27.3	44.3	69.0

Gates, 1991) while a much higher rate of 62.8% was found for this measure in our study. Although abnormality criteria were the same, there were some procedural differences, and the selection criteria varied. The Framingham study used multiple Central Institute for the Deaf (CID) W-22 word lists to establish PBmax whereas AB lists were used in the current study. This would have resulted in a very accurate but lower score than that achieved using the AB lists of the current study, as test results based on phonemic scoring generally produce higher scores than lists using whole word performance scores such as the CID lists (Dillon and Ching, 1995). On the other hand, the Framingham study used a single SSI list presented at 50 dB HL irrespective of the degree of hearing loss. This might be expected to result in a lower SSImax score than achieved in the present study, in which multiple presentation levels based on sensation level relative to the PTA were administered in order to achieve maximum performance. While these procedural differences could explain differences in the maximum scores, the effect on the difference score (PBmax-SSImax or PBmax-MSSImax) on which the CAP abnormality is based should be similar. When the PBmax-MSSImax test results from the present study were reevaluated by excluding participants with PTA  $\geq$ 36 dB HL (as per the Framingham selection criteria), the prevalence rate was still high at 60%.

Variation in participation rates across the two studies also may have contributed to the prevalence rate differences observed. In the Framingham study, 65% of the eligible participants (N = 821) took the SSI test whereas all eligible participants in the present study (N = 1576) had all tests administered. Although the lower participation rate in the Framingham study could have resulted in a selection bias, the

authors were reasonably confident that this was not the case following a review of the normality of their data distributions (Cooper and Gates, 1991). There are therefore no other apparent subject selection or procedural differences between the Framingham and present study to account for the observed prevalence differences. It is still possible, however, that there are other variables such as quality of life and risk factors that could have differed between the two studies leading to differences in test outcomes.

The present study also demonstrated that the number of abnormal test outcomes, which incorporated performance on all speech outcome measures, increased with age. Participants with normal results or only one to two test outcome abnormalities were significantly younger than those with more abnormalities. This phenomenon of increasing CAP abnormality with age has been reported in many other studies, but the complexity and cumulative nature of these abnormalities has not been routinely described (Shiranian and Arnst, 1982; Stach et al, 1990; Cooper and Gates, 1991).

As peripheral hearing sensitivity is also known to decline with age and could therefore confound CAP test results, the impact of hearing thresholds on this outcome was investigated. The test outcomes used in our study already incorporate a recommended corrective factor for hearing loss (Fifer et al, 1983; Yellin et al, 1989; Stach et al, 1990), and therefore to examine the results for any additional influence of hearing loss may seem superfluous. Nevertheless, a comparison of the mean PTA for the better ear and the poorer ear as functions of the grouped test outcomes was performed, and only a small range of averaged thresholds was observed with the poorest outcome being less than 25 dB HL. While there was a significant difference between groups, post hoc tests showed that the relationship between

increased hearing loss and increasing test abnormality reached a plateau when more than three test outcome abnormalities were present. It could, therefore, be concluded that there is an imperfect relationship between increasing hearing loss and increasing abnormality on these measures, that is, increasing CAP abnormality with age is not simply a result of increasing peripheral hearing loss, and, further, that hearing loss appears to have little functional consequence with higher degrees of CAP abnormality. With such a small shift in the mean PTA across grouped test outcomes, it is difficult to determine the real value of this statistically significant finding.

Poor cognitive function and/or deterioration in speech and language are also potential confounders in the interpretation of CAP results. In our study, participants were mostly free of noticeable speech or language impairments although it is acknowledged that the assessment was informal, and they scored well above normal on the MMSE irrespective of test outcomes. Participants were therefore considered capable and competent to perform the tasks. It should also be noted that these participants are community dwelling individuals, the majority of whom rated their health as good or excellent and who did not necessarily report any particular auditory difficulties. The increasing number of abnormal test outcomes with age cannot, therefore, be readily explained by these potential confounders although subtleties of these effects will need to be explored further.

In our data, women were more likely to have normal outcomes, and men were more likely to have a higher prevalence of test abnormalities demonstrated by a weak association (Cramer's  $V = 0.11$ ) between male gender and test outcomes. Previous reports on gender differences in CAP abnormality with age tend to be related to the actual test measure rather than more generic test outcomes described in our study. The Framingham study found no gender difference on two out of three measures whereas other studies have reported higher abnormality rates for either men or women (Shiranian and Arnst, 1982; Jerger et al, 1994; Dubno et al, 1997). On examining two test measures used in the present study, the PBmax-MSSImax and the MDSI test, no gender difference was observed for the former

( $\chi^2 = 1.307$ ;  $p > .05$ ), in keeping with the Framingham report. A significant gender difference did exist for the MDSI ( $\chi^2 = 29.64$ ;  $p < .001$ ), consistent with gender differences previously reported for the original DSI test (Jerger et al, 1994). The significance of the poorer performance by men on the MDSI test, thought to reflect CAP activity at a more cortical level, is difficult to determine. The Framingham study chose to use the Staggered Spondaic Word test as their dichotic measure and found no gender differences (Cooper and Gates, 1991). For the purpose of examining the prevalence of CAP abnormality by gender, it is our conclusion that the variation in outcomes associated with individual test measures most likely underlies the weak association between gender and the number of test abnormalities.

Finally, when the grouped test outcomes were examined as right ear only, left ear only, or binaural abnormalities, a significant increase in binaural abnormality with age was seen. This is not surprising given that, as the number of test abnormalities increases beyond four, abnormality in both ears occurs, and, as already noted, increasing complexity of test outcomes is also associated with increasing age. This cumulative ear abnormality effect has not been widely investigated although certainly the binaural abnormality with age has been reported for the SSImax measure (Stach et al, 1990).

Our data indicate that CAP abnormality is a highly prevalent condition in this older community-based population, when using the common prevalence definition of abnormality on any one of a number of measures, in one or both ears. Defining prevalence in this way may overestimate the true prevalence of a disease (Turner, 1991). An alternative would be to refer to the minimum prevalence rate, which was defined in our study as abnormality on all measures. Whether this reflects "true" prevalence is also debatable. It would of course be preferable in such calculations to use a single measure, guaranteed to encompass the whole of the auditory system, that was known to have high sensitivity and specificity. The diffuse and diverse nature of central auditory dysfunction, and thus the lack of a definitive test for CAP abnormality, makes this quest for the single perfect measure of prevalence impossible to achieve. It may therefore be

far more productive to examine the significance of CAP abnormality with age using the proposed grading system rather than prevalence figures alone. Comparison of the subject characteristics for the normal and abnormal outcomes groups will be the subject of further report.

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