Risk Markers for the Graded Severity of Auditory Processing Abnormality in an Older Australian Population: The Blue Mountains Hearing Study

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Abstract

A recent report from a population-based survey of hearing loss in 2015 older adults showed that the overall prevalence of central auditory processing (CAP) abnormality was high at 76.4% using abnormality on one or more of seven speech-based test outcomes as the criteria. The present study grouped these test outcomes to reflect increasing severity of CAP abnormality and examined the relationship between this graded dependent variable and 16 independent variables. Logistic regression modeling suggested that moderate and severe CAP abnormality increased with age and was associated with increased hearing handicap, and men were more likely than women to show severe abnormality. While 98.5% of the population passed a cognitive screening assessment, declining cognitive function was still associated with the increased likelihood of CAP abnormality.

Key Words: Aging, central auditory disorders, hearing loss

Abbreviations: AB = Arthur Boothroyd monosyllabic word list materials; BMES = Blue Mountains Eye Study; BMES-2 = the five-year follow-up examinations of the Blue Mountains Eye Study; BMHS = Blue Mountains Hearing Study; CAP = central auditory processing; DSI = Dichotic Sentence Identification test; HHIE = Hearing Handicap Inventory for the Elderly; HHIES = the shortened version of the Hearing Handicap Inventory for the Elderly; MDSI = Macquarie Dichotic Sentence Identification test; MMSE = Mini Mental State Exam; MSSI = Macquarie Synthetic Sentence Identification test; MSSImax = maximum performance score on the Macquarie Synthetic Sentence Identification test; PBmax = maximum performance score on the monosyllabic word list materials; SF-36 = short-form 36 quality-of-life questionnaire; SPSS(NOMREG) = Statistical Package for Social Sciences (nominal logistic regression); SPSS(PLUM) = Statistical Package for Social Sciences (ordinal logistic regression procedure); SSI = Synthetic Sentence Identification test; SSI:ICM = Synthetic Sentence Identification test with Ipsilateral Competing Message
Age-related central auditory processing (CAP) abnormality has been described in many studies with wide variations in reported prevalence (Shiranian and Arnst, 1982; Jerger et al, 1989; Stach et al, 1990; Cooper and Gates, 1991). In a recent report from the population-based survey of hearing loss in older Australians, known as the Blue Mountains Hearing Study (BMHS), the overall prevalence of CAP abnormality among persons aged 55 years or older was found to be high at 76.4%, using abnormality on one or more of seven speech-based test outcomes as the criterion (Golding et al, 2004).

These measures arose from the administration of 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 (Golding, 2001), together with the Arthur Boothroyd (AB) Monosyllabic Word Lists recording from the National Acoustic Laboratories (Travers, 1990). As the MSSI and MDSI emulate the performance characteristics of the original versions (Golding, 2001), participants were categorized as showing evidence of CAP abnormality using the following criteria: (1) if the maximum performance score for the AB Word Lists (PBmax) minus the maximum performance score for the MSSI (MSSImax) was >20% in the right ear or in the left ear (Hannley et al, 1983), or (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), or (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), or (4) if the difference between ears on the MDSI test was 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).

More important than identification of prevalence, however, is the functional significance of CAP abnormality in this age group. If CAP abnormality is found to have no association with other subject variables and if there is no demonstrable disadvantage suffered by its presence, then identifying intervention and preventive strategies becomes redundant. Reports of associations between CAP abnormality and risk markers are limited in the literature to date. Cooper and Gates (1991) used linear regression modeling to examine the relationship between performance scores from their chosen CAP measures and age. They reported that age accounted for a maximum of only 15% of the variability in test scores and postulated that the remainder of this variation arose from other factors that occur as a consequence of living and aging (Cooper and Gates, 1991). They also subsequently reported that performance scores on the Synthetic Sentence Identification test with ipsilateral competing message (SSI:ICM) were significantly decreased in women who had a history of heart attack or stroke but found no such association in men (Gates et al, 1993).

A relationship between CAP abnormality and cognitive decline in an older population has also been studied with evidence to date suggesting that these conditions may be concomitant in some but certainly not all cases (Jerger et al, 1989; Gates et al, 1995; Strouse et al, 1995). CAP abnormality has also been reported to precede the onset of dementia in some cases (Gates et al, 1996). More recently, Wiley et al (1998) reported that after adjusting for hearing loss, deteriorating age-related performance scores for word recognition in competing noise were observed, a finding more evident in men than in women. The authors indicated that the combined effects of age, gender, and hearing loss for frequencies up to 8000 Hz only accounted for approximately 50% of the variability in participant word recognition scores. Other factors such as age-related changes in central auditory processing pathways should therefore be considered as possible contributors.

CAP abnormality, defined as reduced performance on specific measures of auditory processing, was found associated with an increased perceived hearing handicap as measured by the Hearing Handicap Inventory for the Elderly (HHIE) (Ventry and Weinstein, 1982) when using the DSI test (Jerger et al, 1990; Chmiel and Jerger, 1996). There was, however, no association found between CAP abnormality and hearing handicap when the SSI test was used (Strouse et al, 1995).

Other factors such as increased systolic blood pressure, or history of hypertension, cardiovascular disease, smoking and alcohol consumption, diabetes and serum lipid levels have been associated with peripheral hearing loss in some but not all studies (Weston, 1964; Rosen et al, 1970; Gates et al, 1993; Brant et al, 1996; Cruikshanks et al, 1998; Dalton et al, 1998; Popelka et al, 2000; Itoh et al, 2001; Mitchell, 2002). Whether these factors are also associated with CAP abnormality, however, is not known.

We aimed in the present study to examine the relationship between the dichotic speech-based CAP test outcomes stratified into four groups (i.e., all normal, 1–2 test abnormalities, 3–4 test abnormalities, 5–7 test abnormalities) and selected possible risk markers including self-reported hearing loss and selected lifestyle variables. We assumed for the purpose of our study that the four-way stratification reflected increasing severity of CAP abnormality. The groups were thus: normal (i.e., no abnormality), mild, moderate, and severe CAP abnormality. Two main-effects multinomial logistic regression models were used to assess the predictive power of the independent variables to identify category of membership correctly.

**METHODS**

**Subjects**

The BMHS, conducted during 1997–1999, 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 widely reported longitudinal study of eye and health-related changes in an older population (Mitchell et al, 1995; Attebo et
The BMHS, conducted in conjunction with the five-year follow-up examinations of the BMES (known as BMES-2), examined 2015 people aged 54–99 years (mean 69.84 years; SD 8.56). Of the 2015 participants, 439 were excluded from taking the CAP test battery for the following reasons: (1) by the application of hearing loss criteria (N = 216); (2) because no hearing thresholds were obtained, thus negating calculation of speech presentation levels (N = 12); (3) poor eyesight or written/spoken language difficulties (N = 55); (4) incomplete assessments (N = 56); (5) frailty (N = 31); (6) inadequate test time (N = 25); or (7) because speech measures were unable to be completed (N = 44). While all 1576 participants who were administered the CAP abnormality test battery were eligible for the analysis described here, a complete dataset was available for only 1192 participants (75.6%) because of missing data on certain independent variables. The 1192 participants with complete data included 696 women (mean age 68.2 years, SD 7.6) and 496 men (mean age 68.3 years, SD 7.7). There was no significant age difference between participants with and without complete data using an independent samples t-test (t[1572] = 1.56; p > 0.05). No significant gender difference between the two groups was observed (χ² = 0.144; df = 1; p > 0.05). There were 273 participants with normal test outcomes, 345 with mild CAP abnormality (i.e., 1–2 test abnormalities), 311 with moderate abnormality (i.e., 3–4 test abnormalities), and 263 with severe abnormality (i.e., 5–7 test abnormalities). There were also no significant differences between the two groups with respect to grouped test outcomes (χ² = 2.608; df = 1; p > 0.05). While imputation of the missing independent variable data was considered, we felt this step was unnecessary because of the relatively large size of the study sample.

**Procedures**

There were 11 categorical independent variables entered to the models: (1) “Do you feel you have a hearing loss?” (Yes, n = 529; No, n = 663), (2) “gender,” (3) “history of stroke” (Yes, n = 75; No, n = 1117), (4) “diabetes” as diagnosed by a doctor and/or evident by fasting glucose levels >7 mmol/L (Yes, n = 114; No, n = 1078), (5) “employment” (still employed, n = 232; Other, n = 960), (6) “living alone” (Yes, n = 866; No, n = 326), (7) “hypertension,” systolic blood pressure >160 mmHg or diastolic blood pressure >90 mmHg or a history of high blood pressure, treated with medication (Yes, n = 466; No, n = 1011), (8) “cardiovascular disease,” history of angina and/or heart attack (Yes, n = 181; No, n = 1011), (9) “never smoked” (True, n = 623; Other, n = 569), (10) “current smoker” (Yes, n = 96; Other, n = 1096), and (11) “alcohol intake” (None, n = 251; Light 1–6 drinks/week, n = 499; Moderate 7–27 drinks/week, n = 410; Heavy ≥ 28 drinks/week, n = 32). The five continuous variables entered into the model were age, the score from the shortened version of the Hearing Handicap Inventory for the Elderly (HHIE-S) (mean 5.95, SD 7.89), the cognitive screening test score using the Mini Mental State Examination (MMSE) (Folstein et al, 1975) (mean score 28.7, SD 1.6), systolic blood pressure (mean 147.9, SD 20.5 mmHg), and the summary score from the Short Form 36 (SF-36) quality-of-life questionnaire (Sanson-Fisher and Perkins, 1998; Ware and Gandek, 1998) (mean score 74.4, SD 19.4).

Ordinal logistic regression (SPSS [PLUM] version 11.5) models a graded dichotomous dependent variable on a set of predictors using a series of equations (P [Y < j] = e^u / 1 + e^u; where “u” is the usual linear regression equation, “Y” is the outcome, and “j” indicates the category) (Tabachnick and Fidell, 2001) with the first equation finding the probability that a participant is below the highest category (severe abnormality) and the second equation finding the probability that the participant is below the next category (moderate abnormality). An equation is solved for each category except the lowest, as it is not possible for a case to be below that level. As this form of modeling has limitations in determining whether a significant predictor variable is equally associated across all categories of the dependant variable, a nominal logistic regression model (SPSS [NOMREG]) that provides this detail and that does not assume increasing severity of the condition was also used.

**RESULTS**

The adequacy of the observed and expected frequencies for all independent variable categorical data was confirmed using a series
of cross tabulations. Less than 20% of cells had an observed frequency less than five, with no cells having expected outcomes less than one, and therefore, there was no restriction on the goodness-of-fit criteria used to evaluate the model. There were no violations of the linearity of the logit for any continuous variables used in the model.

Using the ordinal logistic regression technique, the -2 log likelihood final model value of 2905.3 shows a significant difference from that of the intercept only model ($\chi^2 [18] = 385; p < .001$). Goodness-of-fit criteria, where observed and predicted frequencies are compared (and all independent variables were included), showed an excellent fit ($\chi^2 [3555] = 2906; p = 1.00$) by the Deviance and Pearson criteria ($\chi^2 [3555] = 3492; p = 0.771$). The Nagelkerke $R^2$ of 0.295 suggests that 29.5% of the variability in the dependent variable (i.e., severity of CAP abnormality) could be explained by this logistic regression model.

The Wald test of significance on parameter estimates evaluated the contribution of individual predictors to the final model. Table 1 shows that of the 16 independent variables used to predict membership within the four-category dependent variable, only the HHIE-S score (mean 6.0, SD 7.9), the MMSE score (mean 28.7, SD 1.6), age (mean 68.3, SD 7.6), and gender were significant predictors using a $p \leq 0.005$ significance level, chosen because of the large number of predictor variables.

Table 2 shows significant parameter estimates arising from the nominal logistic regression model. The only significant variable across all categories was the MMSE score while HHIE-S score and age were significant predictors of the moderate and

### Table 1. Parameter Estimates for the Main-Effects Ordinal Logistic Regression Model

<table>
<thead>
<tr>
<th></th>
<th>Correlation estimate</th>
<th>SE</th>
<th>Wald test</th>
<th>df</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systolic BP</td>
<td>-0.00</td>
<td>.003</td>
<td>0.38</td>
<td>1</td>
<td>.537</td>
</tr>
<tr>
<td>HHIE-S</td>
<td>-0.03</td>
<td>.009</td>
<td>10.62</td>
<td>1</td>
<td>.001</td>
</tr>
<tr>
<td>SF-36</td>
<td>0.00</td>
<td>.003</td>
<td>4.99</td>
<td>1</td>
<td>.025</td>
</tr>
<tr>
<td>MMSE</td>
<td>0.38</td>
<td>.039</td>
<td>95.58</td>
<td>1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Age (per year)</td>
<td>-0.08</td>
<td>.009</td>
<td>78.76</td>
<td>1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Alcohol (none)</td>
<td>-0.02</td>
<td>.362</td>
<td>0.01</td>
<td>1</td>
<td>.946</td>
</tr>
<tr>
<td>Alcohol (light)</td>
<td>-0.10</td>
<td>.350</td>
<td>0.09</td>
<td>1</td>
<td>.766</td>
</tr>
<tr>
<td>Alcohol (mod.)*</td>
<td>0.29</td>
<td>.349</td>
<td>0.71</td>
<td>1</td>
<td>.401</td>
</tr>
<tr>
<td>Stroke</td>
<td>-0.08</td>
<td>.230</td>
<td>0.12</td>
<td>1</td>
<td>.733</td>
</tr>
<tr>
<td>Social</td>
<td>-0.36</td>
<td>.158</td>
<td>5.15</td>
<td>1</td>
<td>.023</td>
</tr>
<tr>
<td>Hypertension</td>
<td>0.22</td>
<td>.141</td>
<td>2.45</td>
<td>1</td>
<td>.118</td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>0.11</td>
<td>.160</td>
<td>0.47</td>
<td>1</td>
<td>.495</td>
</tr>
<tr>
<td>Lives alone</td>
<td>0.16</td>
<td>.127</td>
<td>1.60</td>
<td>1</td>
<td>.206</td>
</tr>
<tr>
<td>Diabetes</td>
<td>-0.14</td>
<td>.185</td>
<td>0.53</td>
<td>1</td>
<td>.467</td>
</tr>
<tr>
<td>Never smoke</td>
<td>-0.09</td>
<td>.123</td>
<td>0.48</td>
<td>1</td>
<td>.490</td>
</tr>
<tr>
<td>Current smoke</td>
<td>-0.04</td>
<td>.213</td>
<td>0.04</td>
<td>1</td>
<td>.852</td>
</tr>
<tr>
<td>Hearing loss</td>
<td>0.19</td>
<td>.139</td>
<td>1.80</td>
<td>1</td>
<td>.179</td>
</tr>
<tr>
<td>Gender (male)</td>
<td>-0.66</td>
<td>.128</td>
<td>27.06</td>
<td>1</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

* When multiple categories exist, dummy variables were formed for all but one level of the predictor: in this case “heavy alcohol intake.”
severe categories, and gender was significant for the severe category only.

Adjusting for all other variables in the model, the odds in favor of moderate and severe CAP abnormality increased with each additional year of age (for severe: OR = 1.14, 95% CI 1.102–1.178; and for moderate: OR = 1.086, 95% CI 1.053–1.119) and with increasing HHIE-S score (for severe: OR = 1.06, 95% CI 1.02–1.10; and for moderate: OR = 1.05, 95% CI 1.02–1.09). Gender was a significant predictor for the severe category only. Our data suggested that men were substantially more likely to have severe CAP abnormality than women (OR = 4.02, 95% CI 2.48–6.51). The MMSE score was a significant predictor for all categories. For every point increase in MMSE score, the odds in favor of CAP abnormality decreased, with the greatest change in odds occurring for the severe category and the least for the mild category (for severe: OR = 0.49, 95% CI 0.41–0.57; and for moderate: OR = 0.62, 95% CI 0.53–0.73; and for mild: OR = 0.75, 95% CI 0.64–0.88).

In summary, nominal and ordinal logistic regression modeling indicated that moderate or severe CAP abnormality was more likely with increasing age; severe CAP abnormality was more likely in men than women; increasing hearing handicap was associated with moderate and severe CAP abnormality; and finally, declining cognitive function increased the likelihood of CAP abnormality at all severity levels.

DISCUSSION

In this study, we examined the relationship between CAP abnormality and selected subject variables. The independent variables were selected because they had either been previously associated with poor performance on measures of CAP abnormality or were common risk factors associated with peripheral hearing loss but not previously investigated for association with CAP abnormality. Hearing loss was not included as a predictor even though it is often identified as a probable confounder in the interpretation of CAP abnormality. The BMHS population who underwent CAP testing had good hearing with a mean pure-tone average better than 25 dB HL in both ears across all age groups, as reported previously (Golding et al, 2004). While the results from sentence-based CAP measures are resistant to the influence of peripheral hearing loss (Strouse et al, 1995), and indeed the test outcomes utilized in this study were corrected for the level of hearing before classification, a recent study confirmed that mild hearing impairment has no effect on the outcomes of sentence-in-noise tests provided that presentation levels are adequate (Neijenhuis et al, 2004). The addition of measured hearing as a predictor was therefore considered unnecessary and inappropriate.

Variables found to be significantly associated with CAP abnormality were limited to age, MMSE score, HHIE-S score, and gender. Our failure to find significant associations with CAP abnormality among
risk factors associated with peripheral hearing loss, such as history of stroke, cardiovascular disease, hypertension, systolic blood pressure, alcohol, smoking, and diabetes, could suggest that behavioral tests of central auditory processes in general, or perhaps those used in this study, were insensitive to changes at the vascular level. Alternately, the complexities and redundancies within the central auditory pathways might compensate for vascular influences. Only one previous study reported an association between decreased performance scores on a measure of CAP abnormality and history of heart attack or stroke, with the association restricted to women (Gates et al, 1993). Although this relationship was not demonstrated in the present study, it should be noted first that only 6% of participants reported having suffered a stroke and, second, that the results presented here were dichotic outcomes arising from raw test performance scores corrected for hearing loss. This method of reporting test outcomes was then very different to the raw test scores used in the study reported by Cooper and Gates (1991).

The categorical variables reflecting general quality-of-life issues (i.e., living alone and employment) also showed no significant association with CAP abnormality in this study. This nonsignificant finding may have been due to the vague nature of these questions that did not indicate how long the person had been retired or lived alone. The summary score of the SF-36 questionnaire, on the other hand, demonstrated borderline significance (B = -.016, p = .006) as a predictor of severe CAP abnormality in the nominal logistic regression model but was not statistically significant (p = 0.025) in the ordinal logistic regression model. This apparent contradiction was not surprising as the ordinal logistic regression model examined the overall significance of variables in predicting category membership whereas the nominal model examined whether significant predictors were equally significant across all categories of severity. The borderline association between severe CAP abnormality and the SF-36 summary variable may suggest that severe interference with auditory processing may disrupt communication and lead to a subsequent decline in quality of life. While the detrimental effects of increasing measured hearing loss on quality of life have recently been reported (Dalton et al, 2003), the possible association found between severe CAP abnormality and quality of life, independent of measured hearing loss, has not been previously reported. Further clinical studies of this relationship may thus be warranted.

The HHIE-S score, which aims to assess the impact of hearing loss on the emotional and social needs of the individual (Ventry and Weinstein, 1982, 1983), was a significant predictor when CAP abnormality was at least moderate (abnormality observed for three or more test outcomes). It has previously been shown that hearing handicap is a predictor for auditory processing outcomes (Jerger and Chmiel, 1997) with other studies suggesting that this relationship may be evident only when participants are drawn from a clinical population where a high rate of reported hearing difficulties is expected (Strouse et al, 1995). In the present study, 44.4% of participants felt they had a hearing loss, yet the mean pure-tone average was better than 25 dB HL in the poorer ear. The predictive relationship between the HHIE-S score and CAP abnormality therefore suggests that participants feel the impact of CAP abnormality on their emotional and social needs when it is of at least moderate degree. These patients should therefore be assisted in finding appropriate rehabilitative strategies to ensure a better quality of life.

Our study also showed that age was a significant predictor for both moderate and severe CAP abnormality but was not related to mild CAP abnormality. Age has already been identified as a risk factor for measured hearing loss in population studies (Brant et al, 1996; Klein et al, 2001; Mitchell, 2002) and has been considered to account for around 15% of the variability in CAP test scores (Cooper and Gates, 1991). However, age has not previously been identified as a risk factor for moderate and severe CAP abnormality independent of other frequently identified confounding factors such as hearing loss and cognitive change.

Our measure of cognitive function (MMSE score) was a significant independent predictor for all categories of CAP abnormality. An orderly progression in this relationship by severity was seen with the regression coefficient becoming more negative with increasing CAP severity (mild CAP abnormality: B = -.286; moderate CAP
abnormality: $B = -.479$; severe CAP abnormality: $B = -.721$). Although the mean MMSE score for BMHS participants was well within the normal range at 28.7 (SD 1.6), subtle cognitive decline must be considered a risk marker for CAP abnormality.

Gender was the final significant predictor of CAP abnormality identified in this study, with men more likely than women to show severe CAP abnormality. Gender, however, did not predict mild or moderate CAP abnormality. This pattern could suggest that men are predisposed to more severe CAP abnormality, or it could simply reflect the underlying nature of the tests used to establish abnormality, some of which were dichotic and known to show gender bias (Jerger et al, 1994). As gender differences have also been described for measured hearing loss independent of other risk factors (Pearson et al, 1995; Jonsson and Rosenhall, 1998; Mitchell, 2002), this finding warrants further investigation.

This study represents the first comprehensive review of risk markers for CAP abnormality. After adjusting for all other variables in the models, gender, cognitive decline, age, and HHIE-S score were the only CAP abnormality risk markers identified in this population with the impact of these variables most evident for severe CAP abnormality. It should be acknowledged that these models, although relatively comprehensive in terms of the number and range of independent variables entered, explained only 29.5% of the variability of CAP abnormality with other predictor variables remaining unidentified. Further investigation of these factors and the influences of specific tests used to categorize CAP abnormality will be important to understand more fully the significance of these predictor variables.

REFERENCES


