Chapter Eight

Tailoring Hearing Aid and Rehabilitative Interventions to Listeners' Disabilities and Priorities

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Background

Audiology services for hearing-impaired listeners throughout the world share many common features independent of any particular mode of health care funding and delivery. Regrettably, one of these common characteristics is a heavy concentration on the technical aspects of impaired hearing at the expense of the disabilities and handicaps encountered by hearing-impaired listeners as a consequence of that hearing impairment. This is not an attempt to argue that appropriate evaluation of hearing impairment is not an essential component of assessment and a necessary guide to decisions regarding the form and configuration of any management (usually by the provision of personal hearing aids), but rather to suggest that such a focus omits some of the fundamental components and consequences of impaired hearing. Rehabilitative audiology certainly has a higher profile and greater concentration of effort than it did hitherto, but any survey of practice in almost any international context will reveal that the vast majority of professional effort and resources is devoted to the evaluation and management of hearing impairment as opposed to the consequent disabilities and handicaps.

Although the original WHO classification of disabilities and handicaps received widespread endorsement in an international context (see Hétu et al. 1994; Kramer, Kapteyn, Festen and Tobi 1995; Kramer, Kaptyen and Festen 1998; Noble 1983), there was still some divergence in the use of the terminology between practitioners and bodies in the United States and elsewhere. Furthermore, the concepts were essentially negative in nature and perhaps not sufficiently inclusive of the contextual factors which interacted with an impairment to lead to the consequent effects on individuals and their lives. The subsequent initiative which developed the International Classification of Functioning Disability and Health (ICF) moved away from the terms "disability" and "handicap", and whilst they are not direct analogies or synonyms, developed the concepts of "activity limitation" and "participation restriction". The less-than-immediate accessibility (and perhaps clumsiness) of the resultant terminology has hindered its widespread adoption and, more recently, the ICF framework has adopted the position that "disability" serves as an umbrella term for impairments, activity limitations, and participation restrictions". This contribution is not the place to debate the merits or drawbacks of blurring the earlier distinction between disability and handicap (or here activity limitation and participation restriction), and in this context we use the term disability in the all-encompassing manner as envisaged by the latest manifestation of the ICF framework.

In this contribution we aim to put forward a series of examples to demonstrate that a move from concentration on hearing impairment can lead to a greater understanding of its consequences for hearing-impaired listeners, and carries the potential to both evaluate and more optimally configure interventions for such listeners, usually in terms of the provision of personal hearing aids.

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Note: This paper has been completed by Stuart Gatehouse before his death in February 2007.

Self-Report: A Subject-Specific Approach

Self-report questionnaires and inventories to assess hearing disabilities have a long and honourable history (for a review, see Noble 1998). Such enquiries usually take the form of presenting the respondent with a list of scenarios or vignettes which the respondent is asked to rate on one or more dimensions, usually via some form of fixed scale or set of response alternatives. Such an approach makes the implicit assumption that the range of scenarios or vignettes used are applicable to all respondents, and indeed are equally applicable to all respondents. A more tailored approach has been put forward, whereby the hearing-impaired respondents themselves have a role in specifying the items which are to be rated and the dimensions along which they are to be rated (Dillon, James and Ginis 1997; Dillon et al. 1991; Gatehouse 1999). The prime motivation of these initiatives has been to develop tools which are compatible with the constraints of clinical practice, where time does not allow use of inventories with numerous scenarios to capture all of the relevant listening circumstances. The resultant Client-Orientated Scale of Improvement (COSI) and Glasgow Hearing Aid Benefit Profile (GHABP) have been used to evaluate service effectiveness in both Australian (Dillon et al. 1991) and United Kingdom (Gatehouse 2005) contexts. In the UK context, the GHABP has been used to evaluate the contribution of changes in the hearing aid technology employed (simple linear analogue devices as opposed to more complex digital models) and improvements in audiological service delivery (via structured training programs) (see Gatehouse 2005 for further details). Here we wish to evaluate the extent to which instruments with a subject-

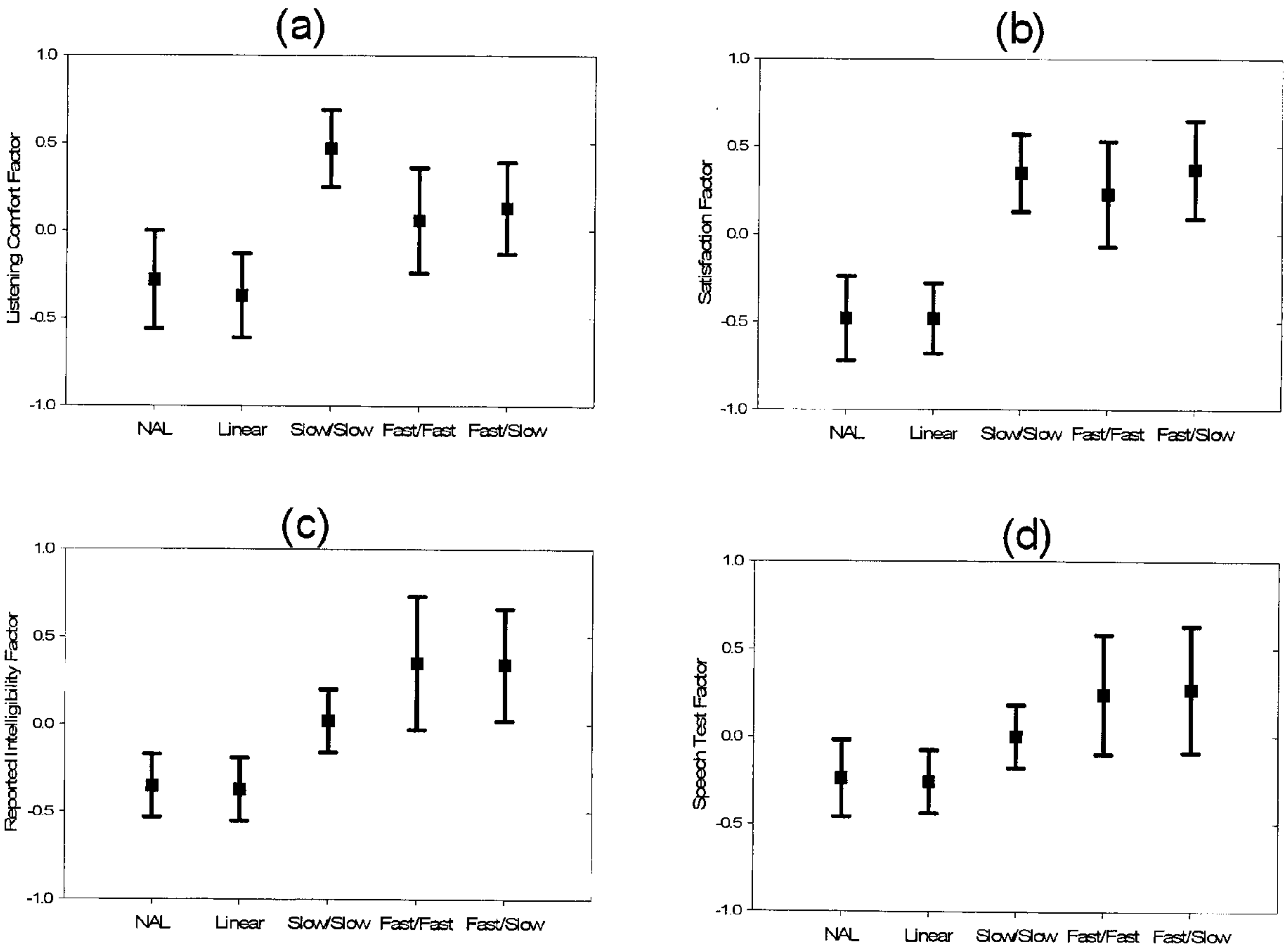

Figure 1. Mean (and 95% confidence interval) of (a) *Listening Comfort* factor, (b) *Satisfaction* factor, (c) *Reported Intelligibility* factor and (d) *Speech Test* factor for the five hearing aid fittings. The Y-axis is a standardised z-score. The figure is re-drawn from Gatehouse et al., 2006a (with permission).

specified contribution to their structure might appear to offer greater (or perhaps reduced) leverage in distinguishing between realistic hearing aid options than might inventories or questionnaires which have a fixed set of scenarios or vignettes, and hence make the assumption regarding equal applicability.

To carry out this evaluation we re-visit the experiment described in Gatehouse, Naylor and Elberling 2006a and Gatehouse, Naylor and Elberling 2006b. The source material should be consulted to gain access to the full details of the experiment. Briefly, the experiment compared five different experimental hearing aid fittings, two of which were *linear* references and three of which had non-linear amplitude compression capacities with differing release-time constants. The non-linear fittings had two channels and are characterized by their release times in the low and high frequencies respectively as (i) *Slow-Slow*, (ii) *Fast-Fast* and (iii) *Fast-Slow*, and can be thought of as representing instantiations of slow-acting automatic volume control processing, fast-acting wide dynamic range compression processing, and a form of hybrid processing designed to minimize upward spread of masking (for details and rationales see Gatehouse et al. 2006a). The two linear references are labeled *NAL-RP* which was a standard recognized clinical prescription for which the listener had access to an active volume control, and Linear which had the same static frequency gain characteristic for a 65 dB SPL input as the non-linear fittings, the same output-limiting settings, and no active volume control (again, for details see Gatehouse et al. 2006a). Listeners wore each of the five experimental fittings for a ten week period in a quasi-randomised quasi-blind crossover design, where outcome was assessed using a variety of self-report instruments and laboratory assessments of speech intelligibility in noise.

The results were represented, following a factor analysis of the numerous measures in the outcome domain, as a series of four factors which were labeled (a) listening comfort, (b) satisfaction, (c) reported intelligibility and (d) speech test performance. Figure 1 shows the mean results for each of the hearing aid fittings across the four outcome factors and is re-drawn with permission from Gatehouse et al. 2006a. We will return to a more detailed consideration of the patterns in figure 1 later in this manuscript, but at present propose to use it as a comparator for an analysis of some of the individual self-report questionnaires which contributed to the eventual three outcome factors in the self-report domain (currently labeled listening comfort, satisfaction and reported intelligibility).

Although the experiment included a relatively wide range of self-report outcome assessments, for this analysis we concentrate on only three. These are the Abbreviated Profile of Hearing Aid Benefit (APHAB) (Cox 1997; Cox and Alexander 1995), the Glasgow Hearing Aid Benefit Profile (GHABP) (Gatehouse 1999) and the Satisfaction with Amplification in Daily Life questionnaire (SADL) (Cox and Alexander 1999). The APHAB is a questionnaire which presents a variety of listening circumstances to a respondent and requires them to rate their self-perceived performance on a pre-specified scale. The questionnaire is completed in the unaided state prior to intervention and re-administered in the aided state at an appropriate juncture following hearing aid fitting. A benefit score is derived by subtracting the two values. The APHAB derives four sub-scales which are labeled (a) ease of communication, (b) reverberation, (c) background noise and (d) aversiveness. The GHABP consists of four pre-specified vignettes and four which the respondent specifies as important to their daily life. Each of these is rated on six dimensions, though for the purposes of this analysis we derive only three sub-scales which are labeled (a) use, (b) benefit (derived from a direct difference question) and (c) satisfaction. The SADL is a questionnaire which is administered following hearing aid fitting and asks respondents to rate the effectiveness or otherwise of their hearing aid fitting on a number of different dimensions. Three sub-scales are derived from the SADL which are labeled (a) positive effect, (b) negative features and (c) personal image. The SADL does derive a fourth scale labeled "service and cost" which does not vary across this experiment, and is not discussed here.

Table 1 shows the mean benefit scores for the sub-scales derived from the APHAB, the GHABP and the SADL for each of the five experimental hearing aid conditions. Note that the benefits for the APHAB aversiveness sub-scale are negative, indicating that respondents rate their listening experience as carrying a penalty in this domain following the provision of a hearing aid. As noted in Gatehouse et al. 2006a, the values in table 1 are comparable to literature values for similar types of hearing-impaired listeners and similar types of hearing aid fittings.

Tables 2, 3 and 4 then show the results of multiple comparison analyses for the sub-scales derived from the APHAB, from the GHABP and from the SADL respectively. Each hearing aid fitting is compared to each of the other fittings and the resultant contrast is corrected for the potential to capitalize upon chance by a series of Bonferroni corrections. Each of the comparisons in

Table 1. Means of the benefit (aided minus unaided)sub-scale scores from the Abbreviated Profile of Hearing aid Benefit (APHAB), the Glasgow Hearing Aid Benefit Profile (GHABP), and the Satisfaction with Amplification in Daily Life (SADL) questionnaire broken down by the five experimental hearing aid fittings.

	NAL-RP	*Linear*	*Slow-Slow*	*Fast-Fast*	*Fast-Slow*
APHAB - ease of communication	31.7	29.4	35.6	31.5	35.4
APHAB - reverberation	34.7	32.4	38.3	39.1	42.0
APHAB - background noise	30.5	29.2	34.1	34.7	38.3
APHAB - aversiveness	-23.4	-25.8	-16.2	-19.2	-17.9
GHABP - use	80.2	82.3	85.3	82.4	81.7
GHABP - benefit	60.3	58.7	64.9	70.0	71.6
GHABP - satisfaction	59.3	57.9	71.8	66.8	69.2
SADL - positive effect	4.80	4.78	5.57	5.15	5.20
SADL - negative features	3.96	3.93	3.36	3.66	3.71
SADL - personal image	5.10	5.04	5.63	5.29	5.45

Table 2. Multiple comparison analyses for the sub-scale benefit (aided minus unaided) scores from the Abbreviated Profile of Hearing aid Benefit (APHAB) across the five experimental hearing aid fittings (following Bonferroni correction).

	Fitting		Fitting			
			Linear	*Slow-Slow*	*Fast-Fast*	*Fast-Slow*
APHAB - ease of communication	*NAL-RP*	Mean	2.25	3.89	.14	-3.71
		Sig	NS	NS	NS	NS
(Mean difference between fittings)	*Linear*	Mean		-6.13	-2.10	-5.95
		Sig		NS	NS	NS
	Slow-Slow	Mean			4.03	.18
		Sig			NS	NS
	Fast-Fast	Mean				-3.85
		Sig				NS
APHAB - reverberation	*NAL-RP*	Mean	2.33	-3.58	-4.45	-7.34
		Sig	NS	NS	NS	p<.05
(Mean difference between fittings)	*Linear*	Mean		-5.91	-6.78	-9.67*
		Sig		NS	NS	p<.01
	Slow-Slow	Mean			-.87	-3.76
		Sig			NS	NS
	Fast-Fast	Mean				-2.89
		Sig				NS
APHAB - background noise	*NAL-RP*	Mean	1.34	-3.54	-4.15	-7.75
		Sig	NS	NS	NS	p<.05
(Mean difference between fittings)	*Linear*	Mean		-4.88	-5.49	-9.09
		Sig		NS	NS	p<.01
	Slow-Slow	Mean			-.61	-4.21
		Sig			NS	NS
	Fast-Fast	Mean				-3.59
		Sig				NS
APHAB - aversiveness	*NAL-RP*	Mean	2.36	-13.25*	-4.21	-5.54
		Sig	NS	p<.01	NS	NS
(Mean difference between fittings)	*Linear*	Mean		-9.61*	-6.57*	-7.90
		Sig		p<.01	p<.05	p<.05
	Slow-Slow	Mean			3.03	3.71
		Sig			NS	NS
	Fast-Fast	Mean				-1.33
		Sig				NS

tables 2, 3 and 4 is labeled as either not achieving statistical significance (NS), or achieving significance at p<0.05 or at p<.01. Table 2 shows that the APHAB ease of communication sub-scale does not achieve statistical significance at p<0.05 for any of the comparisons. The reverberation sub-scale from the APHAB achieves statistical significance at p<0.05 for the comparison between the NAL-RP fitting and the *Fast-Slow fitting,* at p<0.01 for the *Linear* fitting compared to the *Fast-Slow* fitting, but for none of the other comparisons. Thus the reverberation sub-scale from the APHAB only distinguishes between *NAL-RP* and *Linear* versus the *Fast-Slow* fitting. A similar pattern emerges for the background noise sub-scale from the APHAB, which again is only able to differentiate between the *NAL-RP* and *Linear* fittings versus the Fast-Slow fitting. For the *APHAB* aversiveness sub-scale there is a significant difference at p<0.01 for the *NAL-RP* versus the *Slow-Slow* fitting, and for the *Linear* versus the *Slow-Slow* fitting. There are significant differences at p<0.05 between the *Linear* fitting and both the *Fast-Fast* and *Fast-Slow* fittings, but the comparisons between *NAL-RP* and *Fast-Fast* and between *NAL-RP* and *Fast-Slow* do not achieve statistical significance.

Table 3 shows that for the use sub-scale of the GHABP, none of the comparisons achieve statistical significance. This is almost certainly a result of the recruitment criteria for the experiment, where listeners were required to be good consistent users of amplification, and the use variable was effectively at ceiling. The benefit sub-scale of the GHABP shows significant differences between both the *NAL-RP* and *Linear* fittings versus the *Slow-Slow* fitting at p<0.05, and between both *NAL-RP* and *Linear* versus both *Fast-Fast* and *Fast-Slow* at p<0.01. The benefit sub-scale from the GHABP also is able to differentiate between the *Slow-Slow* fitting and both the *Fast-Fast* and the *Fast-Slow* fittings at p<0.05. The satisfaction sub-scale from the GHABP differentiates between both *NAL-RP* and linear versus *Fast-Slow* at p<0.01, and between both *NAL-RP* and *Linear* versus both *Fast-Fast* and *Fast-Slow* at p<0.01 except for the *NAL-RP* versus *Fast-Fast* contrast which only achieves statistical significance at p<0.05. Unlike the benefit sub-scale of the GHABP, the satisfaction sub-scale does not have the leverage to distinguish between Slow-Slow versus either *Fast-Fast* or *Fast-Slow.*

Table 3. Multiple comparison analyses for the sub-scale benefit (aided minus unaided) scores from the Glasgow Hearing Aid Benefit Profile (GHABP) across the five experimental hearing aid fittings (following Bonferroni correction).

Fitting			Fitting			
			Linear	*Slow-Slow*	*Fast-Fast*	*Fast-Slow*
GHABP - use	*NAL-RP*	Mean	-2.05	-5.12	-2.17	-1.49
		Sig	NS	NS	NS	NS
(Mean difference between fittings)	*Linear*	Mean		-3.07	-.12	.56
		Sig		NS	NS	NS
	Slow-Slow	Mean			2.95	3.63
		Sig			NS	NS
	Fast-Fast	Mean				.68
		Sig				NS
GHABP - benefit	*NAL-RP*	Mean	1.57	-6.65	-7.73	-11.34
		Sig	NS	p<.05	p<.01	p<.01
(Mean difference between fittings)	*Linear*	Mean		-6.22	-11.30	-12.90
		Sig		p<.05	p<.01	p.01
	Slow-Slow	Mean			-5.08	-6.69
		Sig			p<.05	p<.05
	Fast-Fast	Mean				-3.61
		Sig				NS
GHABP - satisfaction	*NAL-RP*	Mean	1.39	-12.58	-7.52	-9.96
		Sig	NS	p<.01	p<.05	p<.01
(Mean difference between fittings)	*Linear*	Mean		-13.97	-8.91	-11.35
		Sig		p<.01	p<.01	p<.01
	Slow-Slow	Mean			5.05	2.62
		Sig			NS	NS
	Fast-Fast	Mean				-2.43
		Sig				NS

Table 4. Multiple comparison analyses for the sub-scale benefit (aided minus unaided) scores from the Satisfaction with Amplification in Daily Life (SADL) questionnaire across the five experimental hearing aid fittings (following Bonferroni correction).

	Fitting		Fitting			
			Linear	*Slow-Slow*	*Fast-Fast*	*Fast-Slow*
SADL - positive effect	*NAL-RP*	Mean	.02	-.77	-.35	-.41
		Sig	NS	p<.01	NS	NS
(Mean difference between fittings)	*Linear*	Mean		-.79	-.37	-.43
		Sig		p<.01	NS	NS
	Slow-Slow	Mean			.42	.37
		Sig			NS	NS
	Fast-Fast	Mean				-.05
		Sig				NS
SADL - negative features	*NAL-RP*	Mean	.03	.60	.30	.25
		Sig	NS	p<.01	NS	NS
(Mean difference between fittings)	*Linear*	Mean		.56	.27	.21
		Sig		p<.05	NS	NS
	Slow-Slow	Mean			-.29	-.35
		Sig			NS	NS
	Fast-Fast	Mean				-.41
		Sig				NS
SADL - personal image	*NAL-RP*	Mean	.05	-.54	-.20	-.36
		Sig	NS	p<.01	NS	NS
(Mean difference between fittings)	*Linear*	Mean		-.59	-.25	-.41
		Sig		p<.01	NS	NS
	Slow-Slow	Mean			.34	.18
		Sig			NS	NS
	Fast-Fast	Mean				-.16
		Sig				NS

Table 4 shows that the positive effect sub-scale of the SADL is able to distinguish between both *NAL-RP* and *Linear* versus the *Slow-Slow* fitting at $p<0.01$, but none of the other contrasts achieve statistical significance at $p<0.05$. The negative features sub-scale of the SADL differentiates between *NAL-RP* versus *Slow-Slow* at $p<0.01$ and between *Linear* versus *Slow-Slow* at $p<0.05$, but none of the other contrasts achieve statistical significance. A somewhat similar pattern is found for the personal image sub-scale of the SADL which achieves statistical significance at $p<0.01$ in differentiating between the *NAL-RP* and *Linear* fittings versus the *Slow-Slow* fitting, but for none of the other contrasts.

Inspection of tables 2, 3 and 4 would suggest that the GHABP exhibits a greater leverage in differentiating between the hearing aid fittings than does either the APHAB or the SADL. Moreover, comparison between tables 2, 3 and 4 in the current manuscript and tables 10, 11, 12 and 13 in Gatehouse et al. 2006a shows that the patterns of differentiation for the GHABP are almost identical to the patterns that are derived from the composite factor scores, which themselves are based upon a much wider set of outcome measures. Furthermore, if the data in table 3 of the current manuscript are re-computed using only the four pre-specified listening circumstances in the GHABP, the significant differences between the fittings shown currently in table 3 are almost entirely abolished. Thus it would appear that comparison to the GHABP versus the APHAB and the SADL, and the within-GHABP (i.e., its combined pre-specified and subject-specified mode when compared to the pre-specified mode only), strongly suggests that incorporating in an outcome instrument scenarios and vignettes which are known to be relevant to individual hearing-impaired listeners does bring greater leverage and sensitivity. Some caveats however should be noted. The current analysis compares outcome questionnaires with fundamentally different objectives and structures, while the within-GHABP comparison analysis could have its sensitivity reduced because of only four, as opposed to eight, contributing circumstances. However, we contend that when the realities of a clinical environment limit the time and hence the length of any self-report enquiry, it is likely to be more efficient to include an element of subject-specification of appropriate scenarios or vignettes in the construction of any service monitoring instrument.

Candidature as a Pervasive Issue

As described in the previous section, figure 1 shows the mean outcome results for the five hearing aid fittings described in Gatehouse et al. 2006a, for the four composite outcome factors which are labeled (a) listening comfort, (b) satisfaction, (c) reported intelligibility and (d) speech test performance. The pattern of results is diverse with apparently different findings depending on the domain of outcome which is chosen for focus. These are described briefly below and are discussed in more detail in tables 10, 11, 12 and 13 of Gatehouse et al. 2006a. Contrasts that are identified in the discussion below do achieve statistical significance in that formal analysis in Gatehouse et al. 2006a. In terms of listening comfort, the *Slow-Slow* fitting offers on average superior performance to either of the fast-containing rationales (*Fast-Fast* and *Fast-Slow*), which themselves offer superior average performance to either of the linear fittings (*NAL-RP* and *Linear*). In contrast, when one focuses on the outcome domain of satisfaction, there is no differentiation between the three non-linear fittings, but all three are on average superior to the two linear reference fittings. In contrast when one focuses on reported intelligibility, the two fast-containing fittings (*Fast-Fast* and *Fast-Slow*) offer superior average performance to the *Slow-Slow* fitting, which is itself superior on average to the two linear reference fittings. In the laboratory speech-test domain the pattern of findings replicates almost exactly the reported intelligibility findings. Thus this experiment demonstrates that, when averaged across the group of listeners, there appears to be no unequivocal optimum to identify. Rather, the optimum appears to depend on the domain of outcome that is chosen for focus, and hence on what is likely to be of importance to either groups of listeners or individual hearing-impaired people. Not only does there appear to be no panacea rationale (Naylor 2005), but even if there were such a panacea rationale, it would depend on what the particular objectives of any intervention were designed to be. Leaving aside for the moment the question of whether the four outcome domains identified in Gatehouse et al. (2006a) might be an over simplification of the disabling effects of a hearing impairment, the question arises as to whether it is likely to be possible to determine in advance the priorities of either groups of hearing-impaired listeners or individual hearing-impaired people prior to intervention so that the fitting and processing features of any provision can be optimized. Although the results from Gatehouse et al (2006a) concentrate on release times in amplitude compression systems, we can identify no conceptual reason as to why the findings should be peculiar to that particular parameter and should not generalize to all sets of hearing aid fitting and processing features. We find it difficult to identify any hearing aid feature which can be realistically regarded as unequivocally carrying benefit to all hearing-impaired listeners without the potential to carry penalties to some proportion of the target population. Furthermore we find it difficult to identify any hearing aid features where the potential benefits and penalties are located in any one single outcome domain. While we do not seek to claim that the outcome domains identified in the pragmatic factor analysis in the Gatehouse et al. (2006a) experiment would form a complete description of the disabling effects of a hearing impairment (indeed see a later section in the current manuscript for a discussion of other potentially relevant domains), we have interrogated the current data set to determine whether any of the assessment instruments have the potential capacity to distinguish between individual listeners for whom say, listening comfort would be a priority at the expense of speech intelligibility. We have failed to do so. We therefore suggest that it is an urgent research need to develop and validate methods to identify the needs and priorities of hearing-impaired listeners, at either the group or the individual level, so that fitting and processing features available in today's flexible devices can be selected at the outset so as not to deliver penalties rather than benefits to our clinical populations.

The experiment described in Gatehouse et al. (2006a) had objectives beyond the documentation of benefits, and they included issues of candidature – i.e., what are the pre-existing characteristics of hearing-impaired listeners which are likely to lead them to gain benefits from particular features (Gatehouse et al. 2006b). The candidature domains in Gatehouse et al. (2006b) were diverse and we describe them here only briefly. Table 5 shows a schematic representation of the influences of some candidature dimensions and their direction of action. For simplicity we have amalgamated this representation over the four outcome domains in table 5, which itself is derived from tables 6, 7, 8, 9 and 10 of Gatehouse et al. (2006b). The candidature domains represent a number of factors. The first of these is labeled 'slope and dynamic range' which carries higher values the more sloping the audiogram from low frequencies to high frequencies, and the more restricted the dynamic range between threshold of hearing and threshold of uncomfortable listening (at high as opposed to low frequencies). The domain labeled 'auditory lifestyle and demand' is derived from a questionnaire assessment of the range and importance of listening circumstances which respondents encounter in everyday life. A higher value represents a more varied auditory environment and a greater range of importance of those environments. The two factors labeled 'dosimeter between-frame variability' and 'dosimeter within-frame variability' represent values which emerge from a week's data-logging of the auditory environments in everyday life (see Gatehouse et al. 2006b for details). The 'between-frame' variable represents the slower changes across the course of the day, and the 'within-frame' variable represents variations in the acoustical environment across shorter time scales. The variable labeled 'cognitive function' is derived from a letter and digit monitoring task with greater values representing greater degrees of cognitive capacity. The variable labeled 'spectral and temporal smearing' represents the extent to which hearing-impaired listeners are susceptible to the artificial degradations in the spectral and the temporal contrasts in a speech signal with greater values representing greater susceptibility (one of the hypothesized consequences of aggressively applied multichannel fast-acting wide dynamic range compression is a reduction in such spectral and temporal contrasts). Finally, the variable labeled 'upward spread of masking' is a measure of hearing-impaired listeners' susceptibility to artificial increases in the level of low frequency speech sounds relative to the high frequency components (presumably as a result of widened auditory filters at the higher frequencies). A higher value of the variable represents greater susceptibility.

Table 5 shows that good performance with the two linear reference fittings is inversely related to the slope and dynamic range variable and the auditory lifestyle demand variable, and both the between-frame and within-frame variability variables. In contrast, each of the non-linear fittings is associated with greater values of slope and dynamic range, greater values of auditory

Table 5. Schematic representation of the influences on composite outcome (amalgamated over Listening Comfort, Satisfaction, Reported Intelligibility, and Speech Test performance) of the various predictor variables (data is derived from tables 6, 7, 8, 9 and 10 of Gatehouse et al. 2006b)

	NAL/Linear	Slow-Slow	Fast-Fast	Fast-Slow
slope & dynamic range	↓	↑	↑	↑
auditory lifestyle and demand	↓	↑	↑	↑
dosimeter between frame variability	↓	↑		
dosimeter within frame variability	↓		↑	↑
cognitive function		↓	↑	
effect of spectral & temporal smearing			↓	
upward spread of masking				↑

lifestyle and demand from the questionnaire. There are differing relationships for the non-linear slow fitting as opposed to the non-linear fittings which contain at least one fast element, with the slow fitting being associated with greater degrees of slow changes in the environment, and the fast containing fittings with the more rapid changes in auditory environment. These findings are entirely consistent with a natural interpretation of the objectives of slow-acting automatic volume control fittings and fast-acting wide dynamic range compression fittings. Analysis of the data was not able to find any items in the auditory lifestyle and demand enquiry which were able to distinguish between environments with slow as opposed to fast changes, and it is clearly incompatible with clinical practice to require potential hearing aid candidates to wear a noise monitoring facility for a week before a particular feature could be activated or deactivated. Although not necessarily yet at the point of clinical feasibility, modern digital hearing aids are likely to carry the capacity to themselves gather information regarding the environments within which they are required to function and hence to provide service practitioners with informed advice regarding the activation or deactivation of features.

There are patterns of cognitive capacities and impaired psychoacoustics across the fittings, but time and space in this contribution do not allow consideration of their findings – further details are available in Gatehouse et al. (2006b). However the motivation in including the full set of predictors in table five is to demonstrate the wide diversity of influences that can bring leverage to bear on the extent to which hearing-impaired listeners can benefit from, or be penalized by, the activation of a particular hearing aid feature. Again, we contend that the findings and likely influences of the diverse sets of domains are unlikely to be restricted to release times in compression hearing aids and can see no reason why other features should not be similarly implicated, although we as yet have no experimental evidence to substantiate that contention. We do though however argue that the diversity of outcome coupled with the diversity of potential dimensions which can influence the benefits and penalties that can accrue from hearing aid fitting and processing features should make candidature for those features a prime objective of future research, and should already receive consideration as to the ways in which they might be incorporated both formally and informally into clinical practice environments.

The Diversity of Disability

In the hearing aid experiment in the preceding sections, the outcome measures were collapsed into four statistical factors, three in the self-report domain and one based upon laboratory tests of speech intelligibility. That amalgamation was based on a statistical criterion designed to represent the data across the five different hearing aid fittings in a manner which was as parsimonious as was practicable. It was not designed to be a comprehensive representation of the disabling consequences of impaired hearing and should not be thought of as such. In contrast, the Speech Hearing, Spatial Hearing and Qualities of Hearing questionnaire (SSQ) was designed to be a more comprehensive representation of auditory disability (Gatehouse and Noble 2004; Noble and Gatehouse 2004). Across a group of 135 attendees at an audiology clinic prior to hearing aid management, the SSQ identified a multiplicity of effects on both speech-hearing, spatial-hearing and various qualities of hearing which are systematically related to both hearing impairment (Gatehouse and Noble 2004) and configuration of that impairment in terms of intra-aural asymmetry as a preliminary index of binaural hearing capacity (Noble and Gatehouse 2004). Furthermore, the range of items in the SSQ (and in particular those items which do not necessarily concentrate on reports of speech intelligibility in environments which are essentially static and predictable) appear to exert substantial leverage on an independent measure of the handicapping effects of impaired hearing (Gatehouse and Noble 2004; Noble and Gatehouse 2004). Thus it would appear that the construct of auditory disability has many components and dimensions beyond those traditionally considered, and that these dimensions do exert leverage on the ultimate effects of impaired hearing on the abilities of listeners to carry out the requirements of their everyday lives.

Furthermore the non-traditional elements in the SSQ reveal benefits of a particular management strategy (bilateral as opposed to unilateral fitting of hearing aids) that do not necessarily emerge in self-report measures that concentrate on the more traditional aspects of reported speech intelligibility (Noble and Gatehouse 2006). Thus it would appear that an enquiry which encompasses the additional dimensions within auditory disability does allow the benefits (and indeed potential penalties) of management strategies to be observed. The data reported in Noble and Gatehouse (2006) analyzed the SSQ at the individual item level, as is appropriate for an initial exploratory enquiry. A more parsimonious representation of the SSQ using a series of ten pragmatic sub-scales was derived in Gatehouse and Akeroyd (2006), and the reduced complexity of those pragmatic sub-scales still allows the patterns of benefit following bilateral fittings to emerge.

We here report some preliminary findings from an experiment which attempts to investigate the potential leverage that might be exerted by listeners' attentional and cognitive capacities on their reports of auditory disability as assessed using the SSQ. Briefly, the subject sample consists of 342 respondents who are drawn from a stratified sample of the Glasgow population, such that there is an over-representation of younger more hearing-impaired people, and older less hearing-impaired people. This is designed to allow any effects of attentional and cognitive capacities to emerge and not be pre-empted by the age of the respondents. Some background biographical information on the respondents is available in table 6 in terms of their age, their better ear average hearing level, and their poorer ear average hearing level (averaged across the frequencies of 500, 1000, 2000 and 4000 Hz). The data set consists of both normally hearing people, and people with hearing impairments who would be deemed appropriate candidates for intervention and rehabilitation using audiology services.

Attentional capacities were assessed using the Test of Everyday Attention (Robertson, Ward, Ridgeway and Nimmo-Smith 1996). The individual subtests within the Test of Everyday Attention (TEA) are listed in table 6 as are the mean and standard deviations of the subject scores. The TEA consists of some tests that are administered using purely visual presentation, some which are administered using audio presentation, and some which use dual modality presentation. The visual tests include searching of maps for symbols, searching of quasi telephone directories for particular entry patterns, as well as ability to follow symbol sets in a counting exercise. The auditory tests include tests of sustained attention and similar abstract manipulations in the auditory domain. Time and space precludes a detailed description of the TEA in this contribution and readers are referred to Robertson et al. (1996) for further details.

Table 6. Descriptive data (mean and standard deviation) for the 342 listeners, covering age, better and poorer ear hearing levels averaged over 500, 1000, 2000 and 4000 Hz, and the score from each of the subtests in the Test of Everyday Attention (TEA).

	Mean	S.D.
Age - years	66.12	8.56
Better Ear Average - dB HL	26.46	15.82
Poorer Ear Average - dB HL	34.91	20.72
Map search - 1 minute score	31.04	12.17
Map search - 2 minute score	55.57	15.46
Elevator counting score	6.92	.35
Elevator counting with distraction score	6.39	3.27
Visual elevator score	7.23	2.80
Visual elevator - seconds per switch	4.88	1.93
Elevator counting with reversal score	2.94	3.29
Telephone search time per symbol	4.05	1.30
Telephone search decrement on time per symbol	3.11	3.97
Lottery score	9.36	1.34

For the purposes of the current preliminary analysis the data from the TEA are subject to a series of factor analyses. Firstly, the tests which use only visual presentation are inspected, and from that analysis two factors emerge. We label these (a) visual search and (b) visual executive control. The "visual search" factor is loaded heavily by the map and telephone search subtests, while the "visual executive control" factor is loaded heavily by the visual elevator task. We regard these measures as indicators of attentional capacities which are not necessarily specific to audition, but which find their expression via vision-only presentation. As such they can be regarded as representing the capacities which a listener can bring to bear on a variety of tasks, which might potentially be outside the auditory domain. A second factor analysis is conducted which uses only those variables from the TEA which are presented using the audio-only modality. From this analysis a single factor emerges which we label 'auditory attention'. We regard this factor as representing attentional capacities that might rely on specific auditory functions, though we discuss the implications of that assumption following the presentation of our results.

The data are analysed using a stepwise multiple regression approach, with each of the pragmatic subscales from the SSQ as the dependent variable. Table 7 shows the mean and standard deviation of those subscales for the current data set. The stepwise regressions then proceed in a hierarchical manner, with firstly the indices from the audiogram representing the better and poorer ear average hearing levels inspected and entered into the regression if they meet a $p<0.05$ criterion. A second hierarchical step then inspects the two non-specific (visual) factors from the TEA, and again they are entered into the regression if they meet an entry criterion of $p<0.05$. Only in the third step in the hierarchy is the auditory variable from the TEA inspected and allowed to enter the regression if it meets the entry criterion of $p<0.05$. This hierarchical approach is designed to

Table 7. Descriptive data (mean and standard deviation) over the 342 listeners for the ten pragmatic sub-scales derived from the Speech-hearing, Spatial-hearing and Qualities of hearing (SSQ) questionnaire

	Mean	S.D.
Speech in quiet	8.13	1.79
Speech in noise	6.07	2.29
Speech in speech contexts	6.55	2.39
Multiple speech streams & switching	5.45	2.67
Location	7.23	2.28
Distance & movement	6.93	2.34
Sound quality & naturalness	8.48	1.65
Identification of sounds & objects	8.49	1.50
Segregation of sounds	7.98	2.20
Listening effort	6.25	2.75

preempt any attentional capacities which might be associated with increases in hearing level prior to inspection of the attentional variables. Furthermore it is designed to pre-empt any influence of specifically auditory capacities by allowing the non-specific (visual) variables to enter the regression equations ahead of the specifically auditory variable.

Figure 2 shows a schematic representation of the results of the stepwise regressions. The data are represented as standardized composite beta coefficients, with three classifications for (a) the influence of the audiogram (the better and poorer ears combined should they both enter into the model), (b) the two non-specific attentional (visual) variables potentially entering the regression should they meet the entry criterion, and (c) the specific auditory variable.

Inspection of figure 2 shows that, as would have been predicted, there are significant influences of the level of hearing impairment on each of the pragmatic sub-scales from the SSQ, with greater degrees of impaired hearing associated with greater reports of disability on the SSQ. We do not separately discuss the effects of better and poorer ear hearing levels (hence asymmetry), but the patterns in the current data set are entirely consistent with those in Noble and Gatehouse (2004). Figure 2 also shows that there are pervasive influences from non-specific (visual) attentional capacities for each of the ten pragmatic sub-scales in the SSQ, such that respondents with lower measured non-specific attentional capacities report greater levels of auditory disability following control for the audiometric indices on the better and poorer ears. The magnitude of these influences is approximately one third to one quarter of the influences of the indices characterizing the level of hearing impairment. Finally, figure 2 also shows that, for two of the SSQ pragmatic sub-scales, there is an additional influence of the specific auditory attention variable. This finding is present despite control for the indices for the audiogram, and the measures of non-specific auditory attention. These two sub-scales are labeled 'speech in speech contexts' for which there is an opportunity for informational as well as energetic masking to emerge, and 'multiple speech streams and switching' where a listener is required to process and switch attention between concurrent multiple auditory input streams. For these two sub-scales the combined effects of the non-specific (visual) and specifically auditory attentional capacities are approximately half of the leverage exerted by the measures of hearing impairment.

It should be noted that our labeling of the factors which emerge from the TEA might be open to question. Evaluation of the subtests within the TEA reveals that the auditory analogues of the visual elevator (executive control) measures have a structure that is essentially more abstract and less face-valid than their visual counterparts. Thus it could be that what we have labeled 'specific auditory attention' might be a surrogate for more abstract attentional capacities. However the interpretation of the results from the TEA, it is an unequivocal finding that the 'specific auditory attention' variable is significantly associated with the two speech domains which involve processing in environments which are perceptually and acoustically more complex and demanding than the other two speech domains labeled

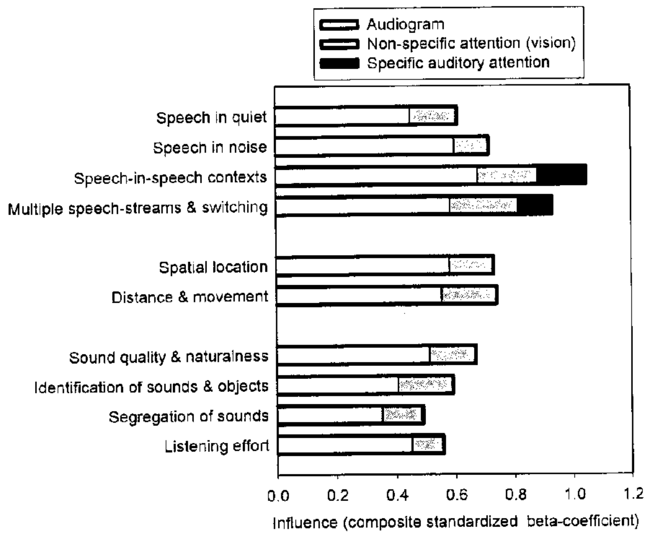

Figure 2. Schematic representation of the results over the 342 for the stepwise multiple linear regressions, with each of the ten sub-scales as the dependant variable. The influence within each of the three variable categories is represented as a composited beta regression coefficient.

'speech in quiet' and 'speech in noise', and might be regarded as essentially dynamic as opposed to static. Thus whatever the appropriate label for the attentional capacities which are assessed using the auditory tests within the TEA, they are implicated in the speech domain, but only in the more perceptually and acoustically demanding circumstances, and their leverage does not emerge in any of the other domains within the SSQ.

The data do demonstrate material influences of attentional capacities which listeners enjoy to the extent to which they report disabilities across the domains of the SSQ, and that these influences are approximately fifty percent of the magnitude of the influences of their impaired hearing status in the more complex speech circumstances. Thus one might now argue that, if these variations in attentional capacities are indeed implicated in auditory disability, then perhaps interventions to attempt to reverse any deficits in attentional capacities also might be regarded as a viable element of auditory rehabilitative interventions as well as interventions to overcome the deficits in audibility consequent to the impaired hearing. Such an argument is entirely consistent with the inclusion in rehabilitative training regimes of specific training in attentional and cognitive capacities in addition to training on purely auditory tasks (Sweetow and Sabes 2006). The current data therefore provide reasoned support for their inclusion in such training programs.

Some Implications for Management

The previous section has identified that there are important influences of attentional capacities on reports of auditory disability, and hence provide some justification for the inclusion of training of such capacities in auditory rehabilitation programmes. Although such training programmes are in their infancy, those that do include such training of attentional and cognitive capacities (Sweetow and Sabes 2006) would appear to offer the same range of training of both specific auditory abilities and separate attentional and cognitive capacities independent of the characteristics of individual hearing-impaired listeners. In the same way as we regard candidature as a pervasive influence in the selection of hearing aid fitting and processing features, we seek to make the case that candidature is also a potentially pervasive influence in the configuration of such training rehabilitation regimes. We do so via the construction of some examples of attentional profiles from the data set in the preceding section. Figure 3 shows box plots for the distribution of the derived factors from the Test of Everyday Attention (TEA) labeled as

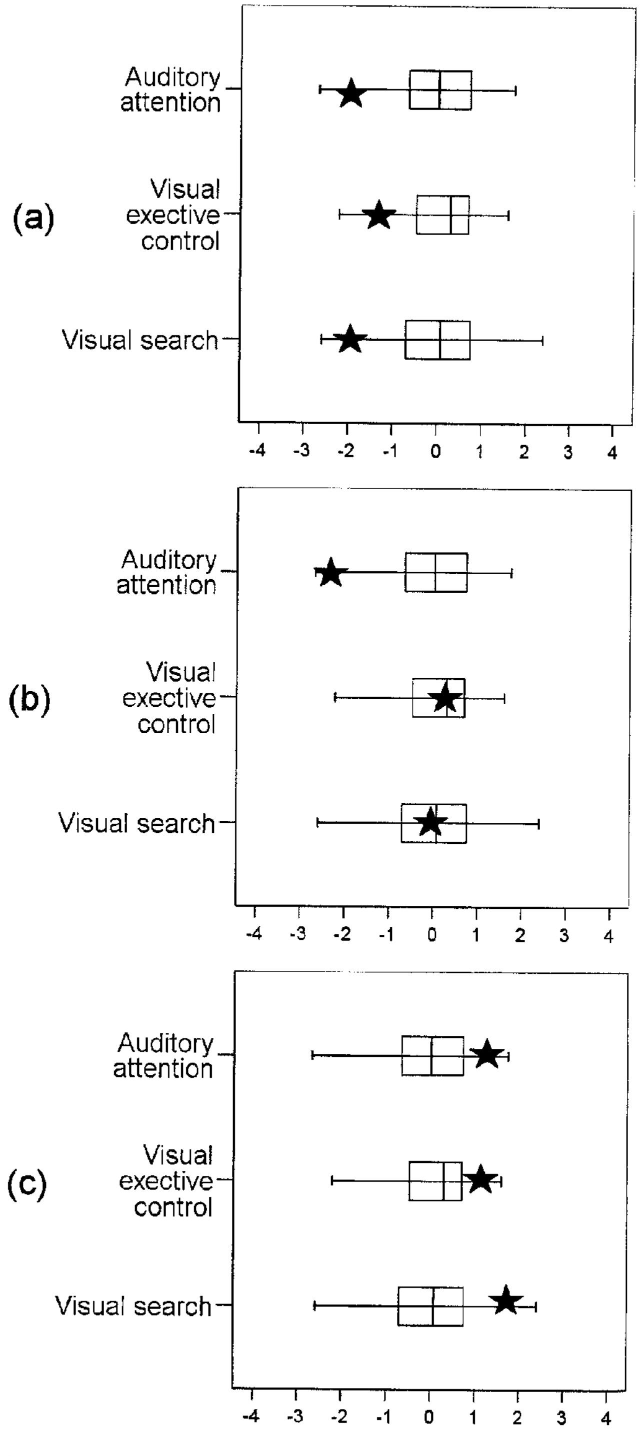

Figure 3. Boxplots for each of the factors derived from the Test of Everyday Attention (TEA) showing illustrative examples of (a) relative deficits for both non-specific (visual) attentional and specific auditory attentional capacities, (b) a relative deficit for specific auditory attentional capacity, but not for the non-specific (visual) capacities, and (c) no relative deficits in attentional capacities.

'visual search', 'visual executive control' and 'auditory attention'. Figure 3 contains examples of three individual hearing-impaired listeners whose hearing levels at greater than 35 dB in their better hearing ear averaged over the frequencies 500, 1000, 2000 and 4000 Hz would make them potential candidates for rehabilitative and hearing aid intervention. Listener (a) exhibits relative deficits (relative to the population distribution) in each of the three attentional domains. One might suggest that listener (a) is a candidate for training in both specifically auditory as well as the non-specific capacities as indexed by the visual attentional performance. In contrast, listener (b) does not exhibit deficits in the non-specific visual domain but does so in the auditory domain. Therefore one might suggest that training in the non-specific capacities might be unlikely to confer significant benefits to listener (b), but that time and resources be concentrated in the purely auditory domain in order to maximize the effectiveness and cost-effectiveness of the resources that are available. In contrast, listener (c) does not exhibit deficits in any of the attentional domains, and indeed would appear to be well served by his/her attentional capacities relative to the population distribution. Therefore one might suggest that rehabilitative intervention be concentrated on aspects of the hearing aids and speech abilities themselves (e.g., concentrated in the purely audiological domain) and that resources devoted to targeting attentional capacities might not be well used. These contentions are of course purely hypothetical and until one has run the controlled experiment the evidence base for targeted training will not be available. However, the contentions do provide a potential explanation for the relative diversity of outcomes which would appear to exist in the evaluations of such training regimes (Sweetow and Sabes 2006), and it is interesting to speculate that an appropriate mix of auditorally based capacities and capacities which are not specific to audition might be the most effective option for future programmes.

Finally, we use the data in figure 4 to raise the contention that the different domains of disability (at least as accessed by the SSQ) need not necessarily have uniform importance to hearing-impaired listeners and hence might not receive uniform attention in the configuration of interventions, and in particular the selection and adjustment of hearing aid fittings and features. Two groups of listeners contribute to the data in figure 4. Firstly, a subset of the listeners in the preceding experiment who have hearing levels in their better ear less than 15 dB HL averaged across the frequencies 500, 1000, 2000 and 4000 Hz are identified, and their mean scores on the ten pragmatic sub-scales from the SSQ are plotted. A second set of listeners who have hearing levels greater than 35 dB across the same frequency range in their better hearing ear are identified (these listeners would be regarded as potential candidates for rehabilitative and hearing aid intervention) and their data are similarly plotted. We then show three examples of listeners with somewhat different profiles on the distributions of the SSQ. Listener (a) has reported abilities for speech in quiet, speech in noise, location, distance and movement, sound quality and naturalness, identification of sounds and objects and segregation of sounds which are close

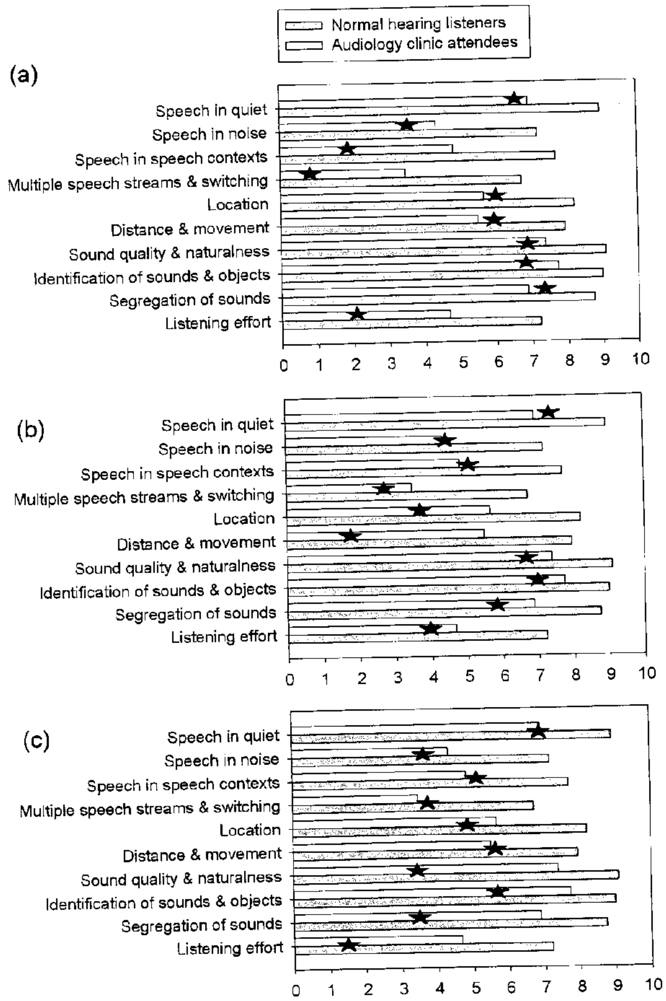

Figure 4. Schematic representation of profiles on the ten pragmatic sub-scales from the Speech-hearing, Spatial-hearing and Qualities of hearing (SSQ) questionnaire showing additional relative deficits for (a) speech in complex listening circumstances, (b) aspects of spatial hearing, and (c) sound quality.

to the mean values for their peers in the hearing-impaired population (note that we are not attempting to suggest that they do not exhibit deficits compared to people with normal hearing across these dimensions, but rather that they do not exhibit deficits which are greater than one would have expected from their level of hearing impairment). They do however, exhibit additional excessive deficits in the domains of speech in speech contexts, multiple speech streams and processing and listening effort. In this particular case, one might suggest that, when selecting and configuring hearing aid-fitting and processing features, they should be selected so as to offer the greatest opportunity to provide benefits in those domains. In contrast, listener (b) only shows deficits in the spatial hearing domains of location and distance and movement (again, note that there are deficits in all domains but that the additional and excessive deficits are located in spatial hearing). Here one might suggest that activating a feature such as highly directional microphones which might distort the spatial environment might carry penalties which would not necessarily serve listener (b) well, although that has yet to receive experimental verification. In contrast listener (c) exhibits additional excessive deficits in domains of sound quality as opposed to speech hearing or spatial hearing domains. In terms of the original experiment described in Gatehouse et al. (2006a) and Gatehouse et al. (2006b), this might be regarded as a " comfort person" for whom maximizing sound quality and listening comfort might be a prime requirement, though again only experimental verification can either substantiate or negate that contention.

Summary

In this contribution we have attempted to provide a series of illustrative examples from experiments to support the contention that aspects of auditory disability can provide a more comprehensive understanding of the consequences of impaired hearing than simple audiometric measures alone. Furthermore, we contend that embracing the complexities involved in auditory disability and the non-auditory influences which we now know exert an influence (such as attentional and cognitive capacities) leads to a better understanding of the consequences of impaired hearing, and offers the potential for maximizing the clinical effectiveness of modern flexible technology and the burgeoning rehabilitative training regimes which are now emerging.

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