International Journal of Audiology

ISSN: 1499-2027 (Print) 1708-8186 (Online) Journal homepage: http://www.tandfonline.com/loi/iija20

Analysis of counted behaviors in a single-subject design: modeling of hearing-aid intervention in hearing-impaired patients with Alzheimer's disease Análisis del conteo de conductas en un diseño unipersonal: Modelo de intervención con auxiliar auditivo en pacientes hipoacúsicos con enfermedad de Alzheimer

John D. Durrant, Catherine V. Palmer & Thomas Lunner

To cite this article: John D. Durrant, Catherine V. Palmer & Thomas Lunner (2005) Analysis of counted behaviors in a single-subject design: modeling of hearing-aid intervention in hearing-impaired patients with Alzheimer's disease Análisis del conteo de conductas en un diseño unipersonal: Modelo de intervención con auxiliar auditivo en pacientes hipoacúsicos con enfermedad de Alzheimer, International Journal of Audiology, 44:1, 31-38, DOI: 10.1080/14992020400022637

To link to this article: https://doi.org/10.1080/14992020400022637

Published online: 07 Jul 2009.

Taylor & Francis
Taylor & Francis Group

Original Article

International Journal of Audiology 2005; 44:31–38

*John D. Durrant**
*Catherine V. Palmer**
Thomas Lunner[†]

*Departments of Communication Science and Disorders and Otolaryngology, University of Pittsburgh, Pittsburgh, USA
[†]Oticon A/S, Research Centre Eriksholm, Snekkersten, Denmark, and Department of Technical Audiology, Linköping University, Sweden

Key Words
Hearing impairment
Hearing aids
Alzheimer's disease
Aging
Mathematical model
Dynamic systems
Single-subject design
Outcomes measures

Analysis of counted behaviors in a single-subject design: Modeling of hearing-aid intervention in hearing-impaired patients with Alzheimer's disease

Análisis del conteo de conductas en un diseño unipersonal: Modelo de intervención con auxiliar auditivo en pacientes hipoacúsicos con enfermedad de Alzheimer

Abstract

Clinical procedures related to patients with Alzheimer's Disease (AD) largely fail to address the patient's hearing. Given the challenges of this population, unconventional indicators of treatment efficacy may be required. Palmer et al (1999) reported on caregiver-tracked behaviors as outcome measures for hearing aid intervention. Using these data, hearing aid use and subsequent behavior was modeled as a first-order dynamic system, characterized by responses following an exponential time course. The results of such modeling suggest predictable outcomes of hearing aid intervention, or at least useful parameters of quantification (e.g. time-constant and steady-state response), permitting critical assessment of effects of intervention on negative behaviors versus hearing aid use, comparisons among behaviors, and/or comparisons of hearing-aid-use patterns and behavior counts among patients. Use in this and other difficult-to-test populations warrant further study to evaluate clinical efficacy of the analysis described.

Sumario

Los procedimientos clínicos relacionados con pacientes con Enfermedad de Alzheimer (AD) fracasan en su intento de medir la audición. Los retos de esta poblacıón obligan a utilizar indicadores no convencionales de eficacia de tratamiento. Palmer et al (1999) reportaron sobre las observaciones que hacía el cuidador responsable, en la conducta del paciente, después de una intervención con auxiliar auditivo. El uso de un auxiliar auditivo y la conducta subsiguiente, se utilizaron para crear un modelo dinámico de primer orden, caracterizado por las respuestas subsecuentes a un tiempo exponencial. Los resultados de este modelo sugieren resultados predecibles en la adaptación de un auxiliar auditivo o al menos, parámetros útiles de cuantificación (p.ej. respuestas constantes o estables) que permiten un análisis crítico de los efectos de la intervención, en conductas negativas versus uso del auxiliar auditivo, en comparación de conductas y/o comparación de los patrones y conductas registradas con uso de un auxiliar auditivo entre los pacientes. El uso del análisis descrito en esta y otras poblaciones difíciles de evaluar demandan mayor estudio para evaluar su eficacia clínica

Loss of hearing with advanced age is well established and broadly accepted as a fact of life. There is widespread suspicion and some evidence suggesting that age-related deterioration of auditory function may extend centrally (e.g. see Gates et al, 1990; Cooper & Gates, 1991). Age-related deterioration in auditory function involves more than decreased sensitivity of hearing (e.g. see Orchik & Burgess, 1977; Jerger et al, 1991). Furthermore, diseases such as Alzheimer's Disease (AD) appear to be associated with increased difficulty with central auditory processing (Weinstein & Amsel, 1987; Gates et al, 1995; Fenton, 1986; Strouse et al, 1995; Sinha et al, 1993).

Conventional wisdom dictates that, in the face of central processing disorders, the appropriateness or value of a hearing aid (HA) is questionable. Does this mean, however, that patients with dementia, such as AD patients, should be considered as unaidable or even less-aidable than non-demented and/or younger patients, a priori? There are several considerations that must be made in addressing this question.

1. Are demented patients less well tested and/or managed clinically in the first place?
2. Is even basic speech recognition performance different for demented patients, thereby potentially diminishing benefit of the major goal of amplification—improving speech audibility?
3. Is (are) hearing aid(s) less beneficial in demented patients, per se, due to putative concomitant central auditory dysfunction affecting yet other auditory capabilities (for instance, speech recognition in noise, high-rate speech processing, and binaural processing)?

ISSN 1499-2027 print
DOI: 10.1080/14992020400022637

Received:
October 29, 2003
Accepted:
March 26, 2004

John D. Durrant
Department of Communication Science and Disorders, University of Pittsburgh, Forbes Tower 4033, Pittsburgh, PA 15260, USA
E-mail: durrant@pitt.edu

Table 1. Mean speech recognition scores and findings of frequency of hearing aid use in samples of patients with Alzheimer' s Disease (AD) and control subjects matched for age and hearing loss, N = 10/group. Tests were conducted under earphones (phones), sound field in quiet (SFQ) and sound field in noise (SFN). Frequencies of hearing loss per group are indicated below

	SRT (dB)		*Speech Recognition (%)*		
Group	*RE*	*LE*	*Phones*	*SFQ*	*SFN*
AD:	25	28	85	74	49
Control:	31	29	82	67	44
Hearing Aid User? *{n}*					
Group		NO	YES		
AD:		9	1		
Control:		4	6		

[Summary of results from Durrant et al, 1991.]

We have previously evaluated questions 1 and 2 (Durrant et al, 1991), and these and other results from our center are summarized in Table 1. Results relevant to question 3, however, are sparse in the literature (Strouse et al, 1995), perhaps belying a general dearth of clinical information. Indeed, results of Durrant and his associates suggested substantial neglect of the hearing handicap in AD patients.

Durrant and coworker's (1991) findings make it difficult to understand the lack of attention to hearing health care in AD patients. Their results derived from a pilot study of 10 AD patients; these subjects were recruited through the university's center for AD research. These cases suffered moderate to severe AD (Mini Mental State Exam [MMSE], Folstein et al, 1975), and they were untreated for their suspected hearing impairments at the time of referral to the hearing clinic. Perhaps counter to expectations, these subjects participated in hearing tests quite well, although certainly needing some encouragement at times. Alzheimer's Disease patients perform relatively well in highly structured situations (Holland et al, 1986), as characterized by hearing tests. For purposes of the study, the subjects were examined according to standard clinical evaluation to determine need and probable benefit of amplification. Results (Table 1) showed nearly identical findings to those of age- and hearing-loss-matched subjects in terms of speech recognition ability in quiet under earphones, in sound field in quiet, and in sound field with competing noise. The sound field tests were administered with speech presented essentially at conversational level—60 dB HL—calibrated at the position of the patient's ear. The results for both AD and control groups suggested that at least the majority of cases in both groups should benefit from amplification. However, the frequency of hearing-aid use showed that, whereas 6 of the 10 controls already were HA users, only one of the AD patients was aided, largely as a result of our interaction with our AD research center in the course of mounting the study. The Fisher-Exact test showed a statistically significant difference between groups ($p \leq .05$). These results indicate that AD patients can be evaluated efficaciously, at least with skilled patient testing, yet they are rarely treated for degrees of hearing impairment for which their age- and hearing-loss-matched non-AD peers are commonly treated.

Palmer et al (1999) subsequently endeavored to determine whether AD patients demonstrate behavioral changes suggesting benefit from HA use. Unlike typical HA studies, the approach focused on caregiver-reported behaviors of the AD patients. An inherent problem in the management of hearing disorders in AD patients is the reliability of information obtained directly from the patient. Patients with AD commonly exhibit various 'negative' behaviors, such as perseverance in manual tasks or spoken phrases, and often saying 'no' to things asked of them to do. Hearing-impaired AD patients also demonstrate negative behaviors commonly associated with hearing loss (e.g. turning the radio/television up too loud or asking for repetition of phrases spoken to them). Palmer and colleagues examined such behaviors by asking caregivers to tally target problem behaviors days before and following intervention with a HA. A typical set of such data for the behavior of their subject identified as #2 is shown in Figure 1. These data illustrate that, as might be expected, there are ups and down in the tally before and after treatment. Patients' behavior tallies naturally vary, and caregivers cannot be expected to capture/report every event faithfully, day after day. Still, these and the results in most cases suggested clear and important trends in patients' behaviors. Over the days leading up to treatment, the behavior tallies were relatively constant or only slowly changing. However, upon intervention, a fairly rapid change in the count occurred, resulting in sharp diminutions of the target behaviors (see Figure 1b). The exact (individual) rate of change appeared to be a function of two or more variables. The first was the patient's reaction to the intervention and perhaps actual perceived benefit. The other was somewhat of an artifact, albeit consistent with the standard of care in hearing aid habilitation/rehabilitation. Conventional practice dictates an adaptive schedule of use of a new instrument, rather than all-out use from day one (see Figure 1a). Thereafter, tallies were seen to settle toward an apparent asymptotic value, substantially below the pre-fitting level (Figure 1). This trend was taken to indicate significant benefit.

The data presented in Figure 1 (and those of other subjects and behaviors observed in the original study), were variable or 'noisy', yet the time course of change in behaviors recorded illustrate more systematic trends than previously appreciated. Therefore, it may be fruitful to try to model any underlying phenomena. Upon inspection, most subjects seemed to indicate an exponential transition response, both in HA use and tallies, followed by an asymptotic steady-state response. Thus, it seemed as if it took some time for the intervention to take full effect, suggesting exponential-like growth of hearing aid use and exponentially decaying tallies of events, despite the prescribed time-table of adaptation (see Figure 1a and Methods).

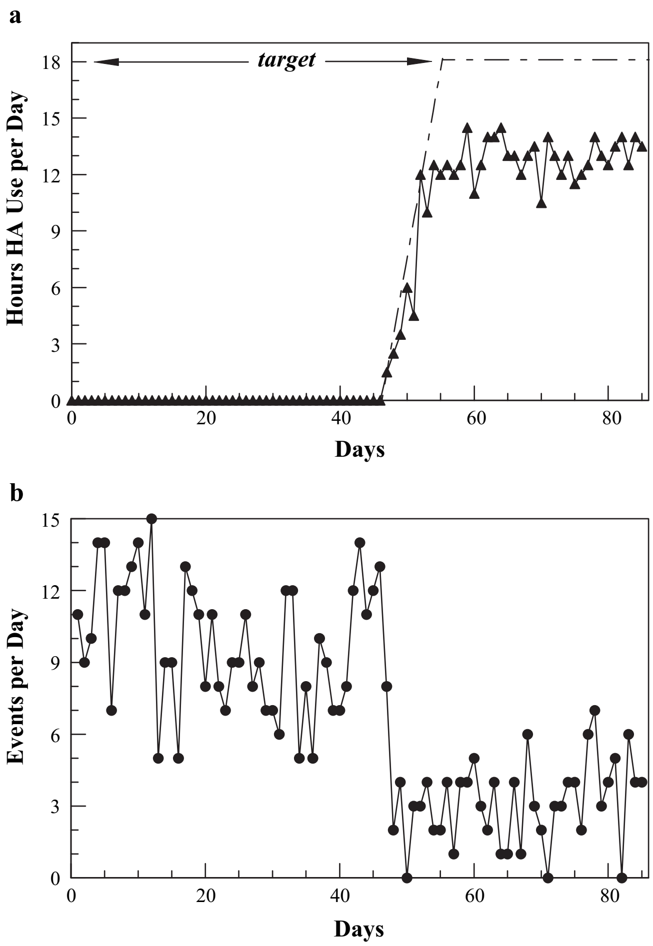

Figure 1. (a) Tracking of hearing-aid use (hours/day). Hearing-aid use commenced on the 47th day of observation. (b) Behavior counts (events per day) of subject's claims of 'can't hear', subject #2. Dashed-line function: linear schedule of hours/day commonly recommended clinically for initial hearing aid use. Original data from Palmer et al (1999) are re-plotted to conform to the format of the current report.

It is well known that, in most systems, the output signal value at a given point in time not only depends on the input signal value, but also on past input values. Systems with this characteristic of 'remembering' old input signal values, wherein the input value right now also affects future values of the output, are called *dynamic systems*. It is reasonable that the system in the case of behavior of the AD subject (measured as hours of HA use per day and tallies of 'negative events' per day), has some kind of memory. On the other hand, it is not reasonable that he/she, in response to an intervention, immediately adjusts his/her behavior; rather, 'old' input values (even behavior before intervention) possibly affects behavior at any given time (again, as manifested both in the HA-use hours and the event tallies per day). This is reminiscent, specifically, of the response of dynamic systems to a step or ramp input (here, HA intervention). For example, in successful hearing aid use there is (at least to some extent) an accrued value of hearing aid use. The patient neither starts immediately with full-time use of the instrument, nor is the final benefit evident from the first-time use.

The potential relevance of the exponential function here goes beyond impressions from inspection of the data; nor is it merely an educated guess. The exponential and closely related functions often fit nature well or are deemed useful (e.g. the logarithmic transform popularized in hearing science—the decibel, a logarithmic transform, and the logarithmic frequency scale). Exponential functions are inherently adaptive in character, and neural discharge patterns, sensations, behavior, and other aspects of nature tend to be more-or-less adaptive, showing asymptotic growth or decay. An example is developmental effects. Eggermont (1988, 1992) applied exponential fits to the development of sensory/auditory evoked potentials to show overall similarities, yet differences, among components per level of the nervous system, thereby providing a parsimonious view of somewhat complicated data.

Such approaches to the analysis of data are valuable for providing useful quantitative outcomes. First, there is the straight-forward aspect of estimating the central tendencies of such data. Fitting of such data is generally accomplished using least-squares methods, by definition a variance-reducing strategy. Second, the parameters of the function fit can provide useful measures, such as the time constant. These values, in turn, may lend themselves to still other mathematical or statistical analyses. Whatever the specific parameters of interest, the advantage is found in the prospect of representing rather complex data by one or a few values. Such an approach can yield results that permit robust opportunities to both quantify and simplify noisy real-world data, fostering bases for critical comparisons among data sets from different subjects/groups and comparisons across diverse measures that follow related time-courses. Interpolation within and extrapolation beyond data sets is another advantage. Lastly, the best-fit function itself may help to define the nature of the underlying behavior.

Returning to AD, per se, there has hardly been a groundswell of interest in the hearing problems of patients with AD, or other dementias for that matter. Therefore, the literature in this area remains sparse. Perhaps a perceived obstacle to systemic study of possible benefits of HA intervention in patients with dementia, especially AD, is concern for the lack of quantitative bases by which to evaluate outcomes. Since the characteristic findings of Palmer et al (1999) suggest a behavior that might be characterized by a mathematical function, the original results of the study were analyzed further in an effort to develop specific parameters of quantification of hearing aid use and caregiver-counted behaviors. The mathematical model applied and the results of data fitting suggest an efficacious approach to data reduction, yielding several parameters as potentially practical measures. Furthermore, as suggested above, the approach permits systematic quantitative comparisons among diverse behaviors within and across subjects. The analysis and results of the fitting of the original data constitute the subject of the present report.

Methods

Summary of Empirical Methods of the Original Study

A brief description of the original methods are described below; please see Palmer et al (1999) for a full description of these methods. A multiple-baseline design across individuals with multiple dependent variables (Bourgeois, 1998; McReynolds & Kearns, 1983) was used to evaluate effects of hearing-aid intervention on the problem behaviors of individuals with AD and hearing loss. Participants consisted of 10 subject-caregiver dyads recruited from several clinics at the University of Pittsburgh. Participants were included in the study if they met the following criteria: (a) a primary medical diagnosis of AD, (b) MMSE score between 12 and 24, (c) results of a significant other's version of the Hearing Handicap for the Elderly (HHIE; Ventry & Weinstein, 1982) revealing a score of $>18\%$, (d) a bilateral sensorineural hearing loss appropriate for the range of amplification provided by the Multifocus hearing aid (Oticon, Inc.), (e) domestic status wherein the subject lived at home with a spouse ($n=7$) or child ($n=3$), and (f) demonstration of 1–4 hearing-related problem behaviors identified by the caregiver. A robust baseline observation period was employed wherein caregivers counted the frequency of one to four hearing-related problem behaviors several times per day. Baseline data (and, thus, pre-intervention data) were collected for 1.5 to 2.5 months. Caregivers were trained in this task by a research associate who visited the home. All hearing aid fitting was conducted in the home as well. After the baseline time period, the hearing-aid intervention began. Caregivers continued to collect daily data on the problem behaviors for approximately 2 months post-treatment.

Dynamic systems and the equations for fitting of the data

Dynamic systems may be characterized by differential equations. It is sufficient for purposes here to consider a first order system (a system with only one memory element). This is familiar in electronics as a simple passive filter, for instance a low-pass filter involving a resistor (R) and a capacitor (C). The first-order differential equation for such a system can be written as

$$\frac{dv(t)}{dt} + av(t) = f(t) \tag{1}$$

where a is a constant, t is the time, $v(t)$ is the output of the system, which can be for example the *Hours HA Use per Day,* as shown in Figure 1a, and $f(t)$ is the driving function, in this case the intervention of treatment with hearing aids. The solution of a first-order differential equation is characterized as the sum of its *particular solution* $v_p(t)$ and its *complementary solution* $v_c(t)$:

$$v(t) = v_p(t) + v_c(t) \tag{2}$$

The particular solution, $v_p(t)$, is usually a weighted sum of $f(t)$ and its first derivative. That is, the particular solution looks like the driving function, $f(t)$. If $f(t)$ is constant, then $v_p(t)$ is constant. In this case the driving function (the HA intervention) may be modeled as a step function, such as:

$$f(t) = \begin{cases} 0 & t < 0 \\ 1 & t \geq 0 \end{cases} \tag{3}$$

The complementary solution of the first-order differential equation has the form:

$$v_c(t) = Ke^{-at/\tau} = Ke^{-t/\tau} \tag{4}$$

where K and τ are constants. Initial conditions will determine the value of the *scaling constant*, K, and the time course of the response is characterized by the *time constant*, τ.

It can be shown that if the initial condition is such that $v(t)=0$ when $t=0$ (e.g. hours of HA use is 0 before the intervention); then, the entire solution (sum of the particular and complementary solutions) of the first-order differential equation, as in Equation 1, can be written in the form:

$$v(t) = u \cdot (1 - e^{-v \cdot t}) \tag{5}$$

where a, u and v are constants. Consequently, if the driving function is a step function, or even a ramped function like the hearing-aid intervention schedule graphed in Figure 1a; the solution can be characterized by the initial transient response, characterized in turn by exponential growth of a particular time constant v (when t is small), followed by the steady state response u (when t is large). Thus, the individual response as a function of time can be described by only two parameters, u and v.

Similarly, it can be shown that the behavior tallies, as in Figure 1b, can be modeled by a first-order dynamic system having an initial constant response, followed by an exponential decay, as the transient response to the HA intervention, and settling to a constant (steady-state) behavior some time thereafter. This response can be described by three parameters representing the initial tally, the time constant, and the final/steady-state tally.

The sample data shown in Figure 1a, again, reflect in part the prescribed schedule of initial HA use (see the dashed-line function in Figure 1a). A simple linear progression of hours/day of HA use is shown, but inspection of the data in Figure 1a and 1b fails to reflect this simple, linear time course. The solution of a first-order dynamic system, as presented above, suggests exponential time courses, if it can be assumed that both behaviors (pattern of hearing aid use and the target behavior tallied) are like impulse responses to the intervention. This, in turn, suggests an approach to analysis of the data, namely computation of the best-fit exponential curves, as follows:

Assumption 1: HA use follows an asymptotic growth characteristic as suggested above; therefore, these data were fitted using the equation

$$\text{hours used} = u \cdot (1 - e^{-v \cdot days}) \tag{6}$$

Assumption 2: the count in 'negative' behaviors is inherently adaptive, and thus also asymptotic, such that

$$\text{events} = a \cdot e^{-b \cdot days} - c \tag{7}$$

where a, b & c are constants (scaling factors) estimated via the curve-fitting algorithm.

Application of the model

To apply the model to the original (raw) data, a mathematical electronic spreadsheet was employed (PSI-Plot, Version 5.52 or later, Poly Software International). Such utilities permit the user to write an equation for the program to estimate constants and evaluate goodness of fit via least-squares analysis. The pre-HA-fitting epoch was fitted by a straight line. The exponential fit was applied to the data starting from the last pre-fit day. An inherent artifact of the exponential fit is a predicted value at time zero that may exceed any practical or real value. However, this was deemed a minor limitation on the assumption that it is the overall fit of the function and its coefficients that characterize the trends of the data and that, in turn, may provide practical quantitative means by which to make comparisons among even remarkably dissimilar measures. The parameters/coefficients of the function may yield useful practical outcome measures, given further work and sufficient data to establish validity and reliability of the approach. The approach is presented here for consideration.

Results and discussion

The raw data (actual HA-use hours and behavioral counts) are re-plotted for subject #2 in Figure 2 with exponential fits of the data. These results suggest that the model yields a reasonable fit of the data, despite the prescribed linear initial-use function (as was presented in Figure 1a). The intervention is predicted from the

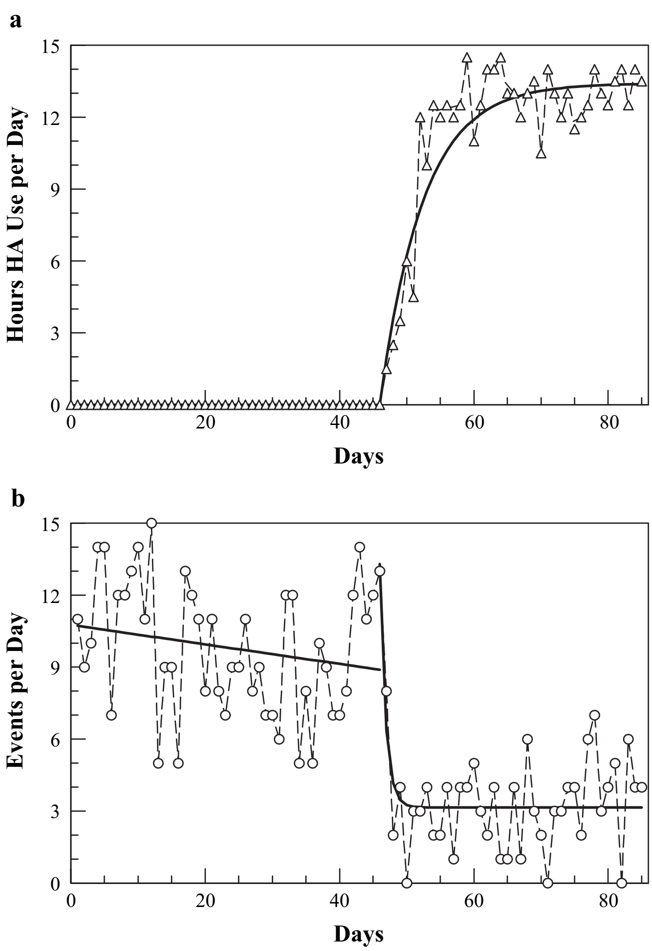

Figure 2. Raw data (dashed line with open symbols) from Figure 1, fitted exponentially (solid line, no symbols): (a) hearing-aid fitted using Equation (1); (b) behavioral tally fitted using Equation (2).

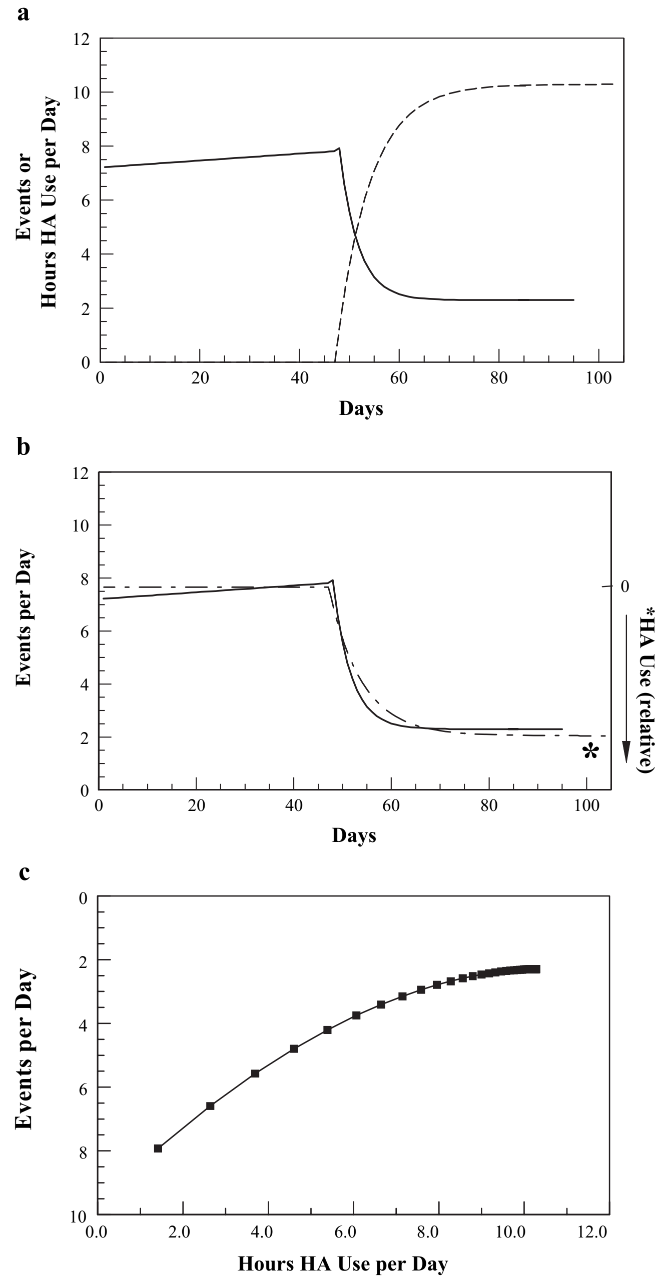

Figure 3. (a) Fits of data from another subject (#4) wherein hearing-aid use (HA, or input function) and behavior counts ('can't hear', output function) are overlaid for comparison. (b) Re-plot of the fitted data from Figure 2a, wherein the input function is inverted and rescaled [HA use (relative)] to permit a more direct comparison with the behavior-tally function. (c) Re-plot of the fitted data (Figure 2b), wherein the behavioral data fit is plotted as a function of the fit for HA use, with inversion of the behavioral data fit for a sense of positive benefit (although certainly subject to interpretation and wherein, the rate of change [behavior count per daily HA use] may be more meaningful than the maximal value [i.e., minimal 'negative' behavior]).

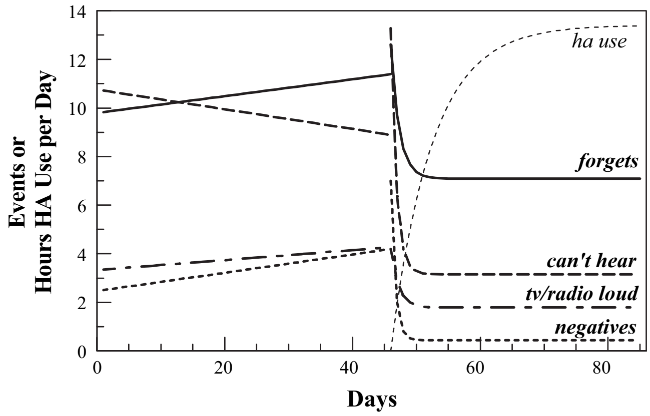

Figure 4. Comparison among fitted data for different behaviors sampled (parameters) from subject #2.

dynamic systems model to follow a course of initial exponential decay of the 'negative' behavior tally, with an asymptotic value at the steady state count. This trend is evident in Figure 2.

Fits of data from another subject (#4) are presented in Figure 3a, illustrating the ability to superimpose the functions of HA use (input) and behavior tally (output) for comparison. Alternative plots of these data are provided in panels *b* and *c* (Figure 3) suggesting additional ways in which the fits may be quantitatively compared, namely for purposes of more direct/detailed comparisons of the time-course of negative behavior tallies and hours of HA use, for instance by simple inversion and rescaling of one function to overlay the other (b) or plotting one parameter against the other (c). Further plots of data from subject #4, who provided an unusually robust number of measures, are provided in Figure 4. First, the fits from Figure 3 are re-plotted for inclusion in the comparison. Second, the fits were computed and plotted for all other data sets, illustrating both the ability to make quantitative comparisons among diverse behaviors (as anticipated) and the saliency of the exponentially decaying behavior in all behaviors sampled (as assumed). This outcome is even more impressive considering that no effort was made to equate actual counts across behaviors; the counts across diverse behaviors naturally differ. The saliency of the model is manifest in the extent to which the exponential functions parallel one another. Figure 5a and 5b provide a comparison of fits of data for another behavior tallied for both subjects #2 and #4 ('forgets'). Note the nearly identical time course of HA-use, although different asymptotic (steady-state) hours/day of use. The results demonstrate somewhat different functions for behavior tallies, most notably in the apparently different time-constants of the two subjects' functions. Subject S2 demonstrated a dramatic reduction of the target behavior, whereas S4 showed a more deliberate time-course of adaptation. Using the conventional criterion of 63% decay (i.e. from electrical engineering), the time constant for the former case was found to be approximately 3 days, whereas it was about 7.5 days for the latter subject—more than double. Whether these are statistically significant differences, or more importantly, clinically significant differences, remains to be evaluated. The purpose here is merely to demonstrate the potential to quantify such differences, thereby providing the

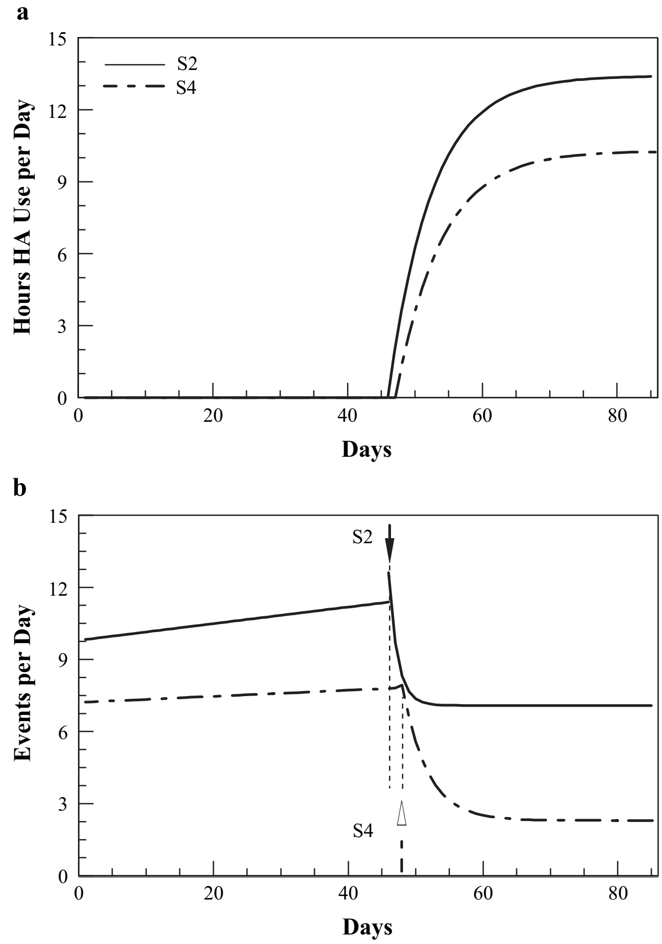

Figure 5. Comparison of fitted functions between subjects #2 (S2) and #4 (S4) whose fitted functions of hearing-aid use follow nearly identical time courses. Output functions suggest somewhat different time-courses of adaptation of the behavior sampled, (forgetting). Starting days of hearing aid use are slightly different and indicated by arrows and parameters (subject number).

bases for systematically analyzing and testing differences in outcomes in future investigations.

While prevalent, the goodness-of-fit demonstrated in the foregoing was not observed for all behaviors and/or in all cases. Figure 6 provides a comparison across a group of five patients for which a common behavioral parameter—forgetting behavior—was tracked successfully. Shown are both fits for HA use and tallies of target events. Again, no effort was made to equate actual baseline counts; rather, the focus is on the salience of the exponential fits across subjects. Several subjects demonstrated similar fits, as described above. However, two subjects' data are remarkably different and noteworthy. First, results for S7 yielded a straight-line fit. In this case, the coefficient b approached zero; any number to the zero-th power equals unity, leaving only the scale factor a. These results suggest that this HA user did not gain substantial benefit, at least not according to the behavior tracked. The hearing-aid-use curve (Figure 6a) illustrates that S7 reached asymptote at 4 hours of use per day

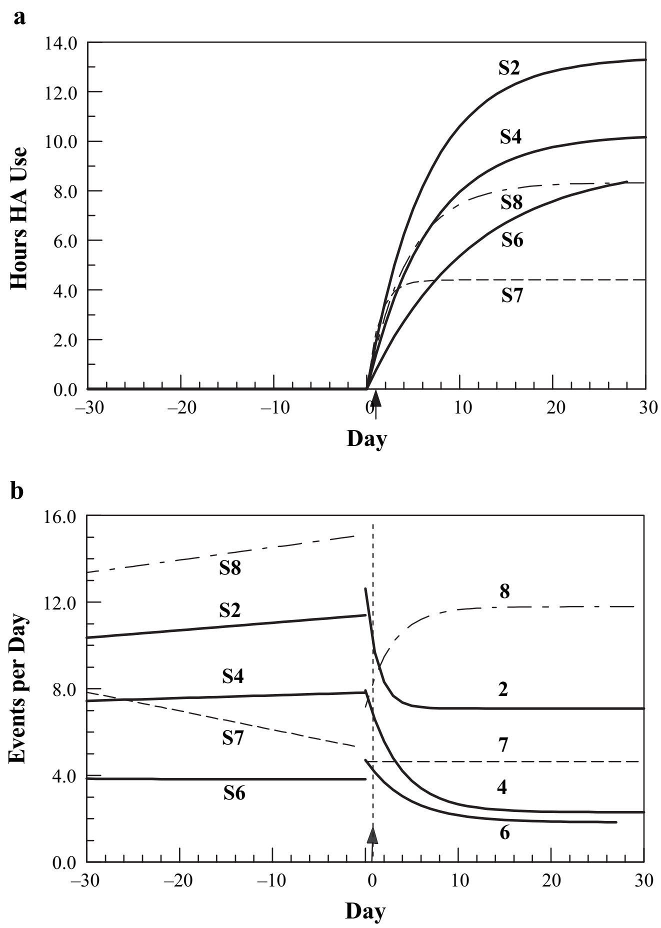

Figure 6. Comparisons among five subjects whose results permitted analyses on a common negative behavior (forgets); the parameters (S#) are the subject' s number, indicated on both the pre- and post-fitting segments for clarity. Counts among behaviors were not rescaled, but all functions have been aligned to a common zero on the time axis wherein day = 0 is the last day pre-fitting (and thus day = 1, 2, ... is the first, second, ... day of hearing-aid use).

which is considerably less than that of other subjects. Lack of benefit in this case might simply reflect such low hours of use, a factor potentially addressable by further clinical intervention. In contrast, subject S8's behavior shows a strange reversal in pattern, yet a net reduction in negative behavior, thus implying significant benefit of HA use. Unlike S8's data, this subject's findings, however, do not mitigate the efficacy of the model. It is tempting to suggest that, for some reason, the mere act of intervention initially caused unusually complete suppression of the target behavior, but this suppression itself started soon to habituate. Meanwhile, HA use, per se, presumably was affecting behavior in a manner typical of dynamic-system response, determining the time-course and long-term impact of intervention.

It would be interesting in future work to assess the relative incidence of the three general patterns of output functions suggested by Figure 6—[1] simple exponential (apparently the dominant function in cases of successful intervention), [2] inverted exponential (still consistent with an interpretation of successful intervention, although representing somewhat more complex behavioral response dynamics), and [3] no-decay functions (suggesting failed intervention). In other words, do these variants express meaningfully different time-courses and/or levels of success of HA fitting and can variants like 'type 3' be used as the basis to plan further intervention and outcome assessment through continued monitoring?

Conclusion

These results demonstrate, overall, the efficacy of modeling the sort of behaviors countable by caregivers of AD patients, vis-à-vis Palmer et al (1999). The approach thus affords systematic analyses of results of hours of hearing-aid use and tallies of targeted behavioral events. Specifically, the approach provides an analytical means of quantitatively characterizing these measures by treating them as samples of responses of a first-order dynamic system. Future studies should be directed toward determining the relative informational value of the fitting parameters, such as the steady-state behavior tally and time-constant. Another potential indicator may be a goodness-of-fit statistic. Such work will be needed to resolve a number of foreseeable practical issues. The following are proposed as key initiatives:

1. Determine the significance of parameters across different counts and perhaps how to choose the best marker among behaviors sampled, or even how to combine different measures for a solitary marker.
2. Evaluate how much baseline is needed, and then how much time post-intervention is needed to estimate the asymptotic tally.
3. Assess how much time resolution (e.g. periods of hours, a day, or days) is needed to get adequate definition of the function and/or estimate of each parameter of interest.

In general, least-squares fitting of data represents a variance-reducing treatment of the data. Consequently, analytical fitting of the empirical data is expected to greatly reduce the number of data points needed for reliable outcomes, making the behavioral measures far less demanding for the caregiver and the overall evaluation process more efficient. Finally, further work is indicated to determine whether this approach will work with other kinds of countable behaviors and whether the approach is equally efficacious in other special or difficult-to-test populations, including patients suffering other dementias, young pediatrics, critically ill patients, and multiply handicapped patients.

Acknowledgements

The authors are indebted to their colleagues Dr Michelle Bourgeois (Florida State University), Dr Paula Davis (Veteran's Administration Medical Center, Pittsburgh, PA), and Ms Sheneekra Adams (HearX, Inc.) without whom the original study upon which this paper is based would not have been possible. We also are grateful to Professor Stig Arlinger, past Editor of IJA, for his thoughtful handling of our manuscript.

References

Bourgeois, M.S. 1998. Functional outcome assessment of adults with dementia. *Seminars in Speech & Language*, 19, 261–275.

Cooper, J.C. & Gates, G.A. 1991. Hearing in the elderly: the Framingham Cohort, 1983–1985, II: prevalence of central auditory processing disorders. *Ear Hear*, 12, 304–311.

Durrant, J.D., Gilmartin, K.J., Holland, A. & Kamerer, D.B. 1991. Hearing disorder management in Alzheimer' s disease patients. *Hearing Instruments*, 42(11), 32–35.

Eggermont, J.J. 1988. On the rate of maturation of sensory evoked potentials. *EEG Clin Neurophysiol*, 70, 293–305.

Eggermont, J.J. 1992. Development of auditory evoked potentials. *Acta Oto-Laryngol*, 112, 197–200.

Fenton, G. 1986. Electrophysiology of Alzheimer' s disease. *Br Med Bull*, 42, 29–33.

Folstein, M., Folstein, S. & McHugh, P. 1975. Mini-mental state: A practical method for grading the cognitive state of patients for the clinician. *J Psychol Res*, 12, 217–225.

Gates, G.A., Cooper, J.C. Jr., Kannel, W.B. & Miller, N. 1990. Hearing in the elderly: the Framingham cohort, 1983–1985. *Ear Hear*, 11, 247–256.

Gates, G.A., Karzon, R.K., Garcia, P., Peterein, J., Storandt, M., Morris, J.C. & Miller, J.P. 1995. Auditory dysfunction in aging and senile dementia of the Alzheimer' s type. *Arch Neurol*, 52, 626–634.

Holland, A., Boller, F. & Bourgeois, M. 1986. Repetition in Alzheimer disease: A longitudinal study. *J Neurolinguistics*, 2, 163–178.

Jerger, J., Jerger, S. & Pirozzolo, F. 1991. Correlational analysis of speech audiometric scores, hearing loss, age, and cognitive abilities in the elderly. *Ear Hear*, 2, 103–109.

McReynolds, L.V. & Kearns, K. 1983. *Single-subject experimental designs communicative disorders*. University Park Press: Baltimore, MD.

Orchik, D.J. & Burgess, J. 1977. Synthetic sentence identification as a function of the age of the listener. *J Am Audiol Soc*, 3, 42–46.

Palmer, C.V., Adams, S.W., Bourgeois, M., Durrant, J. & Rossi, M. 1999. Reduction in caregiver-identified problem behaviors in patients with Alzheimer disease post-hearing-aid fitting. *J Spch Lang Hear Res*, 42, 312–28.

Sinha, U., Hollen, K., Rodriguez, R. & Miller, C. 1993. Auditory system degeneration in Alzheimer' s disease. *Neurology*, 43, 779–785.

Strouse, A., Hall, J. & Burger, M. 1995. Central auditory processing in Alzheimer' s disease. *Ear Hear*, 16, 230–238.

Weinstein, B.E. & Amsel, L. 1987. Hearing impairment and cognitive function in Alzheimer' s disease. *J Am Gerontol Soc*, 35, 274–275.

Ventry, I. & Weinstein, B. 1982. The hearing handicap inventory for the elderly: A new tool. *Ear Hear*, 3, 128–134.