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TNRT profiles with the Nucleus Research Platform 8 system

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Abstract

This study investigates the effect of the Nucleus CI24RE implant's neural response telemetry (NRT) system, which has less internal noise compared to its predecessor, the CI24M/R implant, on the NRT threshold (TNRT) profile across the array. CI24M/R measurements were simulated by ignoring CI24RE measurements with response amplitudes below 50 uV. Comparisons of the estimated TNRTs from the CI24RE measurements and the CI24M/R simulations suggest that, apart from a constant level difference, the TNRT profiles from the newer implant generally would not have differed very much from those of its predecessor. This view was also reflected by principal component analysis (PCA) results which revealed a 'shift' component similar to that reported by Smoorenburg et al (2002). On the whole, there is no indication that current practices of using the TNRT profiles for assisting with speech processor programming need to be revised for the CI24RE implant.

Keywords

Cochlear implant; CI24RE; Neural response telemetry; Evoked compound action potential; TNRT profile; Principal component analysis

The Nucleus CI24M cochlear implant introduced in 1996 features a self-contained system for intracochlear measurements of the electrically evoked compound action potential (ECAP), whose measurement data is sent via back-telemetry to the controlling neural response telemetry (NRT) software. Although the measurement system is easy and reliable to use, it is not without its shortcomings. The measurement amplifier has a noise floor of around 30–40 uV after averaging (Brown et al, 2000), limiting the accuracy in determining the ECAP threshold. Additionally, the amplifier gain can only be reduced from 60 dB to 40

dB when avoiding saturation that would otherwise arise from excessively large inputs, at the cost of a correspondingly poorer signal to noise ratio (SNR). The nominal temporal resolution of the measured neural response was increased by using a double-buffer scheme which in turn introduced nonlinearity complexities when combining the two low-resolution buffers (Lai 2004). The CI24R implant, introduced in 2000 and featuring a smaller receiver/stimulator package as well as a perimodiolar (Contour) electrode array, used the same telemetry circuitry for measuring the ECAP.

The Nucleus Research Platform 8 (RP8) system consisting of the CI24RE cochlear implant, the L34 body-worn speech processor, and the Nucleus Programming Environment (NPE) software (Battmer et al, 2004), was developed specifically for research purposes, such as investigating the effect of an improved measurement amplifier. The CI24RE implant's measurement amplifier has a lower noise floor for the same amount of averaging (around 2 μ V [Patrick et al, 2006]), as well as improved linearity which reduces the susceptibility to saturation. The difference in the measurement noise between the CI24M/R and the CI24RE implants is illustrated in Figure 1. The lower noise floor results in faster measurements, since less averaging is needed to obtain a clear recording of the neural response. In addition, finer gain adjustment settings allow better optimization of the measurements to maximize the SNR. The sampling rate for NRT recordings has also been increased, allowing higher temporal resolution for the measured neural response without having to resort to additional manipulation.

The neural response threshold (TNRT) is usually estimated using either linear extrapolation of the amplitude growth function (AGF), or visual detection of the smallest measurable neural response. The reduced noise floor of the CI24RE implant allows neural responses with smaller amplitudes to be recorded than otherwise possible with the CI24M/R implant. The result should be more accurate estimates of TNRT from either extending the lower portion of the AGF, or a lower visual threshold. Either way, the TNRTs derived from measurements using the CI24RE implant are expected to be different compared to those from the previous CI24M/R implant.

Although the TNRT does not correspond directly to the perceptual threshold, modest correlations between TNRT and map T & C values for the CI24M/R implant have been reported by various studies (e.g. Brown et al, 2000; Hughes et al, 2000; Franck & Norton, 2001; Smoorenburg et al, 2002; Cafarelli-Dees et al, 2005; King et al, 2006; Potts et al, 2007). These have encouraged the increasingly widespread use of TNRT profiles in assisting with speech processor programming, especially for very young children (e.g. Hughes et al, 2000; Mason et al, 2001; Gordon et al, 2002; Kaplan-Neeman et al, 2004) as well as the elderly (e.g. Pedley et al, 2007).

Differences in TNRT between the CI24RE and CI24M/R implants would thus lead to differences in their corresponding TNRT profiles as well. Unless the changes in TNRT values were uniform across the electrode array, resulting in only a level shift in the TNRT profiles, this could change the correlations between the TNRT profiles and map T & C values. This, in turn, could then affect the way the CI24RE implant's TNRT profiles are applied to speech processor programming. There is therefore a clinical interest to know

whether the relationship between TNRT and the map T & C values would be affected by the (more accurate) TNRT values obtained with the CI24RE implant.

This study therefore aims to examine the relationship between the CI24RE implant's TNRT values with corresponding map T & C values, and to investigate whether the CI24RE implant's TNRT profiles differ from those of its predecessor CI24M/R.

Method

Amplitude growth functions (AGFs) from five electrodes (typically e20, e15, e10, e5, and e3) spread across the intracochlear electrode array were obtained postoperatively for each participating CI user. All NRT recordings were made using the forward masking artefact-cancellation paradigm, each averaged over 50 sweeps. The measurement amplifier's gain was kept high (60 dB) whenever possible (while avoiding amplifier saturation) in order to maximize the SNR. The recording site was always located two electrodes basal to the stimulation site (e.g. stimulation on electrode 20, recording on electrode 18). The masker pulse was always 10 current level units larger than the probe pulse. The stimulation levels were reduced in five current level steps to generate the AGF, beginning at the loudest acceptable presentation level (LAPL) as indicated subjectively by the CI user. A stimulation rate of 80 Hz was used by default, but this could be reduced to 35 Hz when necessary to yield a higher stimulation level without exceeding LAPL. This reduction was only necessary with one subject. The TNRT values were then estimated from the AGF by linear regression extrapolation.

The AGFs were collected at regular four week intervals after and including the initial tune-up session (denoted as week 0). The data collection was terminated at week 12 after tune-up.

The map T & C level data for the same electrodes were also collected during the same sessions so as to be able to compare them directly against their corresponding TNRT counterparts. Note that the AGFs at week 0 (tune-up) were indeed based on data collected on that same day rather than from intraoperative data. ACE maps with a stimulation rate of 1200 pps per channel were used for the entire duration of the study.

One of the aims of this study was to compare the TNRT profiles from the CI24RE implant against the TNRT profiles from the predecessor CI24M/R implant. Ideally, such comparisons should be made using data from the two different implants in the same ear, which is impossible in practice. However, it is possible to use the recording data from the CI24RE implant to simulate the data as though it had been recorded with the CI24M/R implant in the following manner:

The main difference between NRT recordings from the two implants lies in the newer CI24RE implant's ability to measure much smaller response amplitudes, compared to the older CI24M/R implant which has a higher noise floor of typically 30 uV to 40 uV (Brown et al, 2000). NRT recordings with the CI24M/R implant are typically made with 100 averages (NRT3.1 software default), while the CI24RE recordings in this study involved only half this amount of averaging. To allow for the likelihood of greater noise due to this difference in averaging, the noise floor threshold was rounded up to a more conservative 50

uV for the simulations in this study. Assuming that measurements with response amplitudes above 50 uV would be similar with either implant, the AGF from the newer CI24RE implant can be truncated below 50 uV to simulate the NRT recordings as though they had been made in the same ear with the older CI24M/R implant. Such simulations would only be approximations as the remaining (untruncated) recordings would still contain less noise than their real CI24M/R counterparts. This will have to be kept in mind when interpreting the data later. Other differences between the generation circuitry for the two implants, such as linearity and resolution, could theoretically also affect the measurements, but these are assumed to have lesser impact than the noise floor.

The truncation process is illustrated in Figure 2. A typical AGF measured using the CI24RE implant is shown in Figure 2, a. Data points above and below 50 uV are distinguished by solid and empty diamonds respectively. The truncated AGF with only data points above 50 uV is shown in Figure 2, b. Truncating the AGF in this manner generally results in the extrapolated TNRT value being shifted higher, as is also illustrated in Figure 2. The exact amount of shift in the TNRT depends on the shape and the rate of growth of the AGF. At higher response amplitudes, the AGF can be approximated by a linear function, whereas at lower response amplitudes, the AGF often exhibits an asymptotic tail towards the x-axis. Differences in the AGF from one site to another would cause the TNRTs from the truncated AGFs to be shifted by different amounts for each site along the array, resulting in the TNRT profiles computed from the complete and the truncated AGFs to be not parallel to one another. Note also that the asymptotic tail at lower response amplitudes means that the slope becomes less steep as responses to higher stimulation levels are omitted from the calculation of the regression line used to extrapolate TNRT. If there were a smaller number of suprathreshold data points in the AGF, the effect of truncating the AGF would be more pronounced (see Figure 2, c and d).

Subjects

Complete TNRT and map data (ACE1200) from a total of 17 subjects from six centers (Hannover, Iowa City, Melbourne, New York, St Louis, and Zürich) were compiled for this study. The subjects were all postlingually deafened adults aged between 27 and 72 years, with less than 20 years of deafness. Their aetiologies are summarized in Table 1.

Results

Truncating the AGF: Estimating the ‘simulated’ CI24M/R TNRT value

As described in the Methods section above, AGFs for the CI24M/R implant were simulated by truncating (ignoring) all response amplitude values below 50 uV. The truncated AGF yields a different TNRT value, denoted as TNRT50. This TNRT50 is typically higher than the corresponding TNRT, particularly when the AGF is not linear down past the point of truncation to the abscissa, such as when an asymptotic tail is present in the AGF at lower response amplitudes. This was generally the case, as can be seen from Figure 3, which plots TNRT versus TNRT50 pooled over all four sessions. The values before truncation (i.e. TNRT) and after truncation (i.e. TNRT50) showed a very good correlation ($R = 0.98$) with

one another, suggesting that the truncation has in general not produced radically different TNRT50 values.

Note that truncation in this manner is only applicable to AGFs with at least two data points with response amplitudes above 50 uV, otherwise, the AGF would no longer be defined after truncation and the TNRT50 can not be computed. As the AGFs were all measured post-operatively with awake subjects, it was not always possible to guarantee that the maximum response amplitude of an AGF would be over 50 uV. Consequently, only 56% of the AGFs remained after truncation. It could be argued that using a lower truncation threshold (e.g. 30 uV or 40 uV) would have resulted in slightly more truncated AGFs. However, the present choice of 50 uV is meant to account for the smaller amount of averaging used with the CI24RE recordings.

Correlations with map T & C levels

The most common form of comparison of TNRT values versus psychophysical map T & C levels found in current literature is simple correlations (e.g. Brown et al, 2000; Hughes et al, 2000; Franck & Norton, 2001; Cafarelli Dees et al, 2005; King et al, 2006). However, level differences in the TNRT, T and C values across subjects need to be taken into account before the data can be pooled together. Otherwise, the resultant pooled data would have greater scatter than appropriate. To take into account level differences across subjects, the following was done:

For each subject, the mean difference between the TNRT and its corresponding T value (referred to as the T-offset) across the array was first computed. This mean T-offset was then added to the T values, effectively correcting the mean level differences between the TNRT and T level profiles across the array. This correction does not change the correlation between the TNRT and T values for a particular subject.

Similarly, the mean difference between the TNRT and its corresponding C value (referred to as the C-offset) across the array was also computed. This mean C-offset was then subtracted from the C values, effectively correcting the mean level differences between the TNRT and C level profiles across the array. As with the T-offset correction, this does not change the correlation between the TNRT and C values for a particular subject. The above corrections to the T and C values are similar to those employed by Franck & Norton (2001), and were computed for both TNRT as well as TNRT50 in order to examine the effect of truncating the AGFs on the correlations with map T & C values.

The offset-corrected map T & C levels yielded correlations of $R = 0.78$ and 0.80 respectively when compared with the corresponding TNRT values (pooled data over all four sessions) (Figure 4). The same offset-corrected map T & C levels produced very similar results when compared with the estimated TNRT50 values, with correlations of also $R = 0.78$ and 0.80 respectively (Figure 5). The similarity between the correlations for both TNRT and TNRT50 indicate that the presence of the smaller response amplitudes below 50 uV measurable with the CI24RE implant has not affected the correlations between TNRT and the corresponding map T & C levels.

Changes over time

Figure 6 illustrates how the averaged TNRT, TNRT50, T and C profiles change over time. Over a period of 12 weeks from tune-up, the average TNRT and TNRT50 values were quite stable, while the average T and C levels typically showed a small but gradual increase (up to 20 current level units) as the subjects adapted to the CI's stimulation.

A one-way analysis of variance showed that the mean differences between TNRT and the map T & C levels did not vary significantly between sessions (T-TNRT: $p=0.004$, C-TNRT: $p=0.006$). On the other hand, the mean differences between TNRT50 and the map T & C levels were not so consistent over the four sessions (T-TNRT50: $p=0.318$, C-TNRT50: $p=0.469$).

Principal component analysis

The data was also subjected to principal component analysis (PCA) to examine the similarities between TNRT, T level, and C level profiles across the array, in the same manner as reported by Smoorenburg et al (2002). The analysis was then repeated for the TNRT50 profiles, compared with the same T level and C level data, in order to assess the difference between TNRT and TNRT50. Typically, only components with eigenvalues >1 are considered to be significant. It is important to note at this point that Smoorenburg et al (2002) used profiles consisting of 20 electrodes, while the data here only involve five electrodes spread out across the array per profile, raising the significance threshold from 5% to 20% of the total variance.

The first two components from PCA of the individual TNRT, TNRT50, T and C data are summarized in Table 2, including also the results from Smoorenburg et al (2002) for convenience. For the present data, only component 1, which accounted for 70.3%, 67.0%, 84.2%, and 77.3% of the total variance for TNRT, TNRT50, T level, and C level respectively, was found to be significant. As expected, given the smaller number of data points per profile, these values are less than those reported by Smoorenburg et al (2002).

Interpretation of the principal components involves plotting them as a function of the electrode number, as illustrated by Figure 7. In all cases, component 1 is fairly constant across the array, suggesting it could be interpreted as an 'offset' or 'shift' component. In Smoorenburg et al (2002), two main components were found for each of the TNRT, T, and C data which were interpreted as a 'shift' and a 'tilt' component respectively.

The individual correlations between TNRT (as well as TNRT50) and the corresponding T and C levels were then examined for component 1, and the results are summarized in Table 3. The correlations between TNRT versus the T & C levels were a modest 0.40 and 0.57 respectively. Similar correlations (0.58 and 0.55 respectively) were obtained for TNRT50 versus the T & C levels. Both sets of correlations compared reasonably well with those reported by Smoorenburg et al (2002). The correlation between TNRT and the C levels for the present data was statistically significant at the 95% confidence level.

PCA was also performed on the collective {TNRT, T, & C} data, as well as on the collective {TNRT50, T, & C} data in the same manner as Smoorenburg et al (2002). Here, only a

single component was found which accounted for 70.4% and 70.7% of the total variance, compared to 94.1% for the first component reported by Smoorenburg et al (2002), as summarized in Table 4. The similarity between the {TNRT, T, & C} and the {TNRT50, T, & C} data sets can also be seen in Figure 8, which also shows that the significant component can clearly be interpreted as a 'shift' component.

Discussion

The truncation process for simulating the NRT recordings from the CI24M/R implant yields only an approximation, as there would still be less noise in the remaining (untruncated) CI24RE recordings than in actual CI24M/R recordings. Consequently, the corresponding TNRT50 estimates, while producing less scatter due to the reduced noise, would at the same time be compromised by being derived using a smaller number of remaining data points. The specific combined effect of the reduced scatter and the reduced number of data points are not investigated further here. It is important to bear in mind that TNRT50 is also approximate in nature.

The NRT profiles from the CI24RE implant have been analysed using various methods which yield different degrees of details.

With simple correlations, no distinction is made between different sites along the electrode array, nor are inter-subject differences accounted for. Nevertheless, the high correlation found between TNRT and TNRT50 suggests that the truncation of the AGF below 50 μ V response amplitude generally resulted in little more than a level shift between TNRT and TNRT50. The observation that TNRT50 was generally larger than TNRT indicates that the truncated portion of the AGF either had an asymptotic nature as the response amplitudes approached zero, or had at least a slope lesser than that of the untruncated portion. Had the AGF been linear with the same slope all the way down to the abscissa, there would have been very little difference between the extrapolated values for both TNRT and TNRT50.

Correlations between TNRT and map T & C levels were similar to those reported in previous studies (e.g. Brown et al, 2000; Hughes et al, 2000; Frank & Norton, 2001). The improved sensitivity of the NRT measurement circuitry has therefore apparently not altered the correlations dramatically. This again suggests that the CI24RE implant's TNRT profiles are merely lower in level, and that the changes in TNRT along the electrode array may possibly be regarded as being uniform. This view is further reinforced by the correlations between TNRT50 and the map T & C levels, which are also similar to those found with the predecessor CI24M implant. Bearing in mind that the TNRT50 values are only approximate in nature, it would seem that truncating the AGF was a reasonable way to simulate the neural response measurements as if they had they been made with the predecessor CI24M/R implant.

The TNRT being smaller than TNRT50 is a direct consequence of the improved measurement sensitivity. However, TNRT remains higher than the behavioral threshold (map T level). A one-to-one correspondence between TNRT and the behavioral threshold is unlikely to be achieved as measurements of the ECAP necessitate a certain degree of

synchrony in firing of the activated neural population, whereas such synchronous activity is probably not required for the perceptual system to detect the activity at the behavioral threshold. The relationship between TNRT and the map C levels is more difficult to determine as the latter is very much subjective in nature. Correlations between TNRT and the map C levels are indirectly an indicator of the relationship between corresponding map T & C levels.

The results over time showed that there were not very large changes in TNRT or TNRT50 over time, suggesting that postoperative measurements of the ECAP are quite stable over time. The observed increases in both T & C levels over the same period are typical of CI users as they adapt to the CI stimulation and are gradually able to accept slightly higher levels of stimulation with time.

PCA provides more information than simple correlations because it also takes into account variations along the electrode array. The overall results (see Table 4 and Figure 8) show that about 70.4% or 70.7% of the variance between either TNRT or TNRT50 and the T & C levels could be explained by a single component, interpreted as a 'shift' component. Given that the TNRT50 results need to be interpreted with care because of its reduced data set after AGF truncation, the similarities between the {TNRT, T, & C} and the {TNRT50, T, & C} data suggest that the missing TNRT50 data has not significantly affected the principal components. Unlike Smoorenburg et al (2002), only a single significant component which accounted for a smaller percentage of the total variance was found here. This is not surprising considering that the present data set is smaller, with only five instead of 20 electrodes to describe the profiles.

The TNRT and TNRT50 data differed slightly from one another in that TNRT yielded significant correlations between its 'shift' component and the corresponding C level, whereas the TNRT50 data, similar to the Smoorenburg et al (2002) data, were not significantly correlated (see Table 3) with either T or C levels. One possible explanation for the improved correlations for the TNRT data could be the greater sensitivity of the CI24RE implant's measurement circuitry, since these significant correlations disappear when the lower response amplitudes were excluded (with TNRT50 as well as the Smoorenburg et al (2002) data) from the analysis. Note however that the TNRT50 data should not be equated with the Smoorenburg et al (2002) data due to the smaller number of electrodes per profile as well as the reduction in TNRT50 data after AGF truncation. This is possibly a reason also for the lack of significant correlations for TNRT50.

Another difference between the Smoorenburg et al (2002) data and the present study is that the former exclusively involved the CI24M implant which had a straight array of full-ring banded electrodes. In the present study, the CI24RE implant is equipped with the perimodiolar Contour/Contour Advance electrode array, which is expected to provide more variation along the length of the electrode array compared to the straight electrode array. For instance, Smoorenburg (2007) more recently reported a 'curvature' component in the map data where the majority (127 versus 88) of the implants had a perimodiolar electrode array. On the other hand, Willeboer & Smoorenburg (2006) involved Contour/Contour Advance electrode arrays but reported only significant 'shift' and 'tilt' components, possibly due to

the smaller population size of only 18 subjects. Unfortunately, the present data with only five data points for representing each profile is insufficient for revealing features more subtle than the 'shift' component, particularly features that are related to longitudinal variations such as 'tilt' or 'curvature'. In fact, from Smoorenburg et al (2002) it could already be seen that the 'tilt' component accounted for a substantially smaller percentage of the total variations than the 'shift' component.

On the whole, PCA results were similar to those found with the CI24M implant, again reinforcing the view that the TNRT profiles with the CI24RE implant have not been significantly altered to provoke any changes in the clinical application of these TNRT profile.

Conclusions

The aim of this study was to determine if the TNRT profiles have changed with the new CI24RE implant compared to its predecessor CI24M/R implant. Truncation of the AGF was employed to produce TNRT50 profiles in order to simulate the TNRT profiles of the earlier implant. Both TNRT and TNRT50 data produced correlations similar to those reported for the CI24M implant, suggesting that, apart from a level change, there are no great differences in the TNRT profiles between the two implant generations.

Due to the reduction in the number of data points representing each profile, principal component analysis was able to only reveal a single principal component, with similar significance to that found for the predecessor implant. Significant correlations found with the map C levels are likely to be related to the CI24RE implant's improved measurement amplifier, but this has little impact on the general observations above. Thus, it is not expected that the use of TNRT profiles in assisting with clinical speech processor programming will be altered greatly for the CI24RE implant.

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Abbreviations

AGF	Amplitude growth function
ECAP	Evoked compound action potential
DSP	Digital signal processor
NPE	Nucleus programming environment
NRT	Neural response telemetry
PCA	Principal component analysis

RP8	Research platform 8
TNRT	Neural response telemetry threshold

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Figure 1.

NRT recordings from typical CI users with the CI24RE (left column) and the CI24M/R (right column) implants for subthreshold as well as suprathreshold input signals. The examples here were selected to have comparable suprathreshold response amplitudes. The recordings were all made with the same 60-dB amplifier gain setting, and involved 50 averages. The second row shows how a response of around 25 uV peak-to-peak amplitude is clearly discernable with the CI24RE implant, but not at all with the CI24M/R implant.

Figure 2.

The original AGF (a) with all data points as measured with the CI24RE implant yields an extrapolated TNRT of 138 CL. The threshold TNRT50 is shifted to 145 CL when the AGF is truncated below 50 uV (b). The truncated AGF simulates the AGF as if it had been measured with the CI24M/R implant. If the highest stimulation level in the untruncated AGF were lower (resulting in less suprathreshold data points), truncating the AGF produces a larger difference between TNRT and TNRT50 (c and d).

Figure 3.

Correlations between original TNRT (untruncated AGFs) data and TNRT50 (AGFs truncated below 50 uV). Note that TNRT50 was generally larger than the corresponding TNRT.

Figure 4.
Correlations between original TNRT (untruncated AGFs) data with offset corrected (left) T levels and (right) C levels.

Figure 5.
Correlations between TNRT50 (truncated AGFs) data with offset corrected (left) T levels
and (right) C levels.

Figure 6.

Average TNRT and TNRT50 profiles appear to be stable over the 12-week period of the study, while average T- and C-levels show a small but gradual increase over the same period.

Figure 7.

Plots of the principal components across the array show how component 1 can be interpreted as an 'offset/shift' component for the individual TNRT, TNRT50, T-level or C-level data.

Figure 8.
Plots of the single principal component of the collective data sets show very similar component values, suggesting that the TNRT and TNRT50 data are very similar.

Table 1

Subjects summary.

Age (years)	Duration of deafness (years)	Aetiology
27	2	Autoimmune
42	7	Unknown
43	5	Unknown
43	2	Measles
43	20	Familial
43	12	Unknown
53	0	Meniere's disease
61	12	Unknown
63	4	Unknown
64	12	Unknown
67	0	Familial
67	2	Unknown
71	6	Trauma
72	8	Ototoxic drugs
72	1	Familial
74	5	Unknown
74	1	Unknown

Principal components analysis results: Component 2 for the present data (black cells) are not significant. The present data's significant components account for a smaller proportion of the total variances compared to those from Smoorenburg et al (2002).

Table 2

	Percentage variance accounted for						
	Present data			Smoorenburg et al (2002)			
	TNRT	TNRT50	T	C	TNRT	T	C
Component 1	70.3	67.0	84.2	77.3	90	90.0	88.3
Component 2	15.0	18.5	10.6	17.0	6.4	6.7	7.5
Sum (significant)	70.3	67.0	84.2	77.3	96.4	96.7	95.8

Table 3

Correlations between TNRT and the corresponding map T & C levels for the CI24RE implant (TNRT), the simulated CI24M/R implant (TNRT50), and the actual CI24M/R implant (Smoorenburg et al, 2002).

Component interpretation	TNRT			TNRT50			TNRT (Smoorenburg et al, 2002)		
	T Level	C Level		T Level	C Level		T Level	C Level	
Shift	0.40	0.57*		0.58	0.55		0.64	0.39	
Tilt							0.82	0.36	

* 0.05.

Table 4

Combining TNRT and map levels, only a single significant principal component was found for all three instances. The overall data with either TNRT or TNRT50 from the present data showed very similar results.

	Percentage variance accounted for		
	Present data		Smoorenburg et al (2002)
	TNRT, T & C	TNRT50, T & C	TNRT, T & C
Component 1	70.4	70.7	94.1