2006

Comparison of NRT based MAPs and preferred MAPs in adult Nucleus CI24 cochlear implant users

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COMPARISON OF NRT BASED MAPs AND PREFERRED MAPs IN ADULT NUCLEUS CI24 COCHLEAR IMPLANT USERS

by

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A Capstone Project
submitted in partial fulfillment of the
requirements for the degree of:

Doctor of Audiology

Washington University School of Medicine
Program in Audiology and Communication Sciences

May 10, 2006

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Abstract: ***Comparison of subjects' preferred MAPs worn in everyday life and MAPs created using electrically evoked compound action potentials using neural response telemetry measures in adult Nucleus CI24 implant users.***

Abstract

Objective: To compare subjects' preferred MAPs worn in everyday life and MAPs created using electrically evoked compound action potentials (ECAP) using neural response telemetry (NRT) measures in adult Nucleus CI24 implant users.

Design: NRT thresholds were measured on all active electrodes using the NRT software (v3.0) on 29 adult subjects. The preferred MAPs had been worn for a minimum of three months in everyday listening situations. Preferred MAPs and NRT based MAPS were created using the R126 programming software. The preferred MAPS were created over 6-8 weeks using behavioral measures. The NRT based MAPs were created using a combination of behavioral information and NRT data.

Results: Three subjects had no measurable NRT responses at their maximum tolerable level. NRT based MAPs were closer to behavioral preferred MAPs when a greater amount of behavioral information was entered to create the MAP. Differences between strategies and rates were also noted. It was found that the Carolyn Brown method tended to underestimate the preferred MAP levels especially at the apical and basal ends of the array. The Cooper-Craddock method typically overestimated the preferred MAP levels at the basal end of the array for the SPEAK strategy and underestimated at the apical end for the ACE 900/1200 Hz strategy. The Carolyn Brown method best predicted the preferred MAP with the ACE 900/1200 Hz NRT MAP. The Cooper-Craddock method best predicted the preferred MAP with the ACE 1800 Hz NRT MAP.

Conclusions: The NRT thresholds can be used in combination with a limited amount of behavioral information to predict MAP T and C levels. The differences between the Carolyn Brown and Cooper-Craddock MAPs shows the importance of behavioral information. In

addition, the behavioral information used in this study was carefully measured and fine-tuned over several weeks. The accuracy of the T and C levels used to create NRT based MAPs may notably effect the NRT based MAP T and C levels. It is important to note that the variability between the NRT methods and for individual subjects between the NRT based MAPs and their preferred MAPS emphasizes the need to obtain additional behavioral information in order to optimize the MAP for the subject's everyday listening situations.

Comparison of NRT Based MAPs and Preferred MAPs in Adult Nucleus CI24 Cochlear Implant Users

Introduction

Programming of the Cochlear Nucleus 24 cochlear implant system involves programming of minimum stimulation levels (T) and maximum stimulation levels (C). Traditional programming techniques for adults with cochlear implants require behavioral measures, such as loudness judgments and counted thresholds (Skinner, Holden, Demorest, & Holden, 1995; Sun, Skinner, Liu, Wang, Huang, & Lin 1998; and Skinner, Holden, Holden, & Demorest 1999). This approach can be time consuming and challenging to do with children and adults who may be unable to give reliable responses. Because of this, there is a need for more efficient fitting techniques.

Programming first involves obtaining threshold and growth of loudness to stimulation on each of up to 22 electrodes. This requires the cochlear implant user to judge the loudness of the stimulation and be able to detect and respond consistently to near threshold level (T level) stimulation. This is done by presenting electrical stimulation below the threshold and slowly increasing the level of stimulation to a maximum acceptable loudness (C level) as judged by the cochlear implant user. Programming of the T levels requires the individual to consistently detect the stimulation and then correctly count the number of stimulations three out of three times. The C levels are programmed at a level so that loud sounds are never too loud when all the electrodes are activated. This programming technique is repeated several times over the first three months of cochlear implant use. The T and C levels can then be further adjusted so that conversational speech is comfortable.

Cochlear Corporation introduced the Nucleus CI24 cochlear implant after receiving FDA approval in 1998. The Nucleus 24 has the ability to measure the electrically evoked compound action potential (ECAP) through software called neural response telemetry (NRT) (Abbas, Brown, Shallop, Firszt, Hughes, Hong, & Staller, 1999). The ECAP is an early potential that occurs within the first millisecond after stimulation (Hughes, Vander Werff, Brown, Abbas, Kelsay, Teagle, & Lowder, 2001). The ECAP is a measure of the synchronous VIIIth nerve fiber activity in response to electrical stimulation (Franck, 2002). It is the most direct measure of auditory nerve activity in implant users (Abbas, Brown, Shallop, Firszt, Hughes, Hong, & Staller, 1999). The NRT system allows for electrical stimulation on one electrode and recording of the neural response on a nearby electrode. Because the neural response is recorded from inside the cochlea, the amplitude of the response is larger than other potentials using surface recording electrodes and is not very susceptible to muscle artifact (Hughes, Brown, Abbas, Wolaver, & Gervais, (2000). Therefore, it does not require sedation and the time needed for testing is fairly short (Brown, Abbas, & Gantz, 1998). The ECAP is recorded as a negative peak (N1) followed by a positive peak (P2). The amplitude between N1 and P2 varies with current or stimulation level across subjects but can reach values of several hundred μV. The ECAP responses on different electrodes can be indicative of differences in the neural population being stimulated (Abbas, Brown, Shallop, Firszt, Hughes, Hong, & Staller, 1999).

There are many possible clinical uses for NRT measures. Perhaps, the most clinically relevant application is to determine if NRT responses could be used in programming cochlear implants. Recently, many papers have been published describing the relationship between NRT data and the MAP T and C levels on subjects' MAPs (Brown, Hughes, Luk, Abbas, Wolaver, &

Gervais, 2000; Hughes, Brown, Abbas, Wolaver, & Gervais, 2000; Franck & Norton, 2001; Seyle & Brown, 2002; Franck, 2002; Craddock, Cooper, et al, 2003).

In a study with twenty children, Hughes et al (2000) compared NRT thresholds with the T and C levels used to construct the preferred SPEAK MAP that the children used on a daily basis. They found that 18 out of 20 NRT thresholds fell between the MAP T and C levels, although this did vary across subjects. Hughes et al explained that enough variability across subjects exists that creating a MAP using only NRT thresholds alone would result in error in many instances (2000).

A similar study by Brown et al (2000), compared NRT thresholds to MAP T and C levels in 44 adult patients. They found that the NRT threshold was consistently between the T and C level or slightly above the C level in a SPEAK MAP. However, they also found a lot of variability among subjects and the correlations were not strong enough to allow the use of NRT thresholds to program MAP levels.

Based on their previous research which found that there is not much variability between electrodes on a single subject, Carolyn Brown and colleagues developed a method to predict MAP levels based on NRT thresholds and minimum behavioral information. First, to predict MAP T-levels, the difference between the measured MAP T level and the NRT threshold on electrode 10 is taken. This number is then subtracted from the NRT threshold on all other electrodes. Second, to predict MAP C levels, the difference between the measured MAP C level and the NRT threshold on electrode 10 is taken. This number is then added to the NRT threshold on all other electrodes.

When this formula was applied to data found in adult and children subjects, the results show that there is a greater correlation between predicted MAP levels and behavioral MAP levels than between NRT thresholds and measured MAP levels. For example, the correlation between predicted MAP T and C levels and measured MAP T and C levels in children were 0.85 and 0.89 respectively. The correlations between NRT thresholds and measured MAP levels in children were 0.699 for T levels and 0.715 for C levels (Hughes, 2000). Data from adults shows that correlations between predicted MAP T and C levels and measured MAP T and C levels were 0.83 and 0.77 respectively. The correlations between NRT thresholds and measured MAP levels in adults were 0.547 for T levels and 0.565 for C levels (Brown, 2000).

Craddock et al (2003) compared the performance between NRT based MAPs and behavioral MAPs in 17 adult subjects. Nine subjects were using a SPEAK coding strategy and eight were using a higher rate ACE strategy. They used the Carolyn Brown recommendations to create their NRT based MAPs. The authors reported that mean T and C levels were in close agreement with the T and C levels from the SPEAK MAPs. For the ACE MAPs, the predicted T levels were in close agreement with behavioral T levels. In addition the predicted C levels tended to overestimate the behavioral C levels, especially in the basal end of the array. They also reported wide variability in individual data between behavioral and NRT MAP levels. The authors concluded that NRT thresholds combined with a limited amount of behavioral information may be used to reasonably predict behavioral T and C levels. From this study Craddock and colleagues (2003) developed another method for creating NRT based MAPs using a slightly different procedure than Carolyn Brown.

The results from these studies have spurred the use of clinical protocols for incorporating NRT in the MAPping of cochlear implants to be developed. The goal of this research project is to assess the usefulness of ECAP thresholds recorded with NRT in predicting an individual’s MAP using two different procedures that are available in the R126 programming software. This study will compare the predicted T and C levels using the Carolyn Brown procedure and the Cooper-Cradock procedure with the subject's preferred MAP T and C levels created from behavioral measures.

Methods

Subjects

Twenty-nine adult Nucleus CI24 cochlear implant users participated in this study. All subjects were implanted at Washington University School of Medicine between January 1, 2003 and July 1, 2005. All subjects received pre- and post-operative services at Washington University School of Medicine. All subjects had used their cochlear implants for at least three months before NRT was collected. Thirteen of the subjects were using an ACE 1800 Hz speech coding strategy. Eleven of the subjects were using an ACE 900 or 1200 Hz coding strategy. One subject used an ACE 500 Hz coding strategy. Four of the subjects used a SPEAK 250 Hz coding strategy. Each of these MAPs was worn for a minimum of three months.

Procedures for Obtaining Preferred MAP Data

The clinical procedure used for programming the MAP T and C levels was developed at Washington University over the past 17 years and is thoroughly documented (Skinner, Holden, Demorest, & Holden, 1995; Sun, Skinner, Liu, Wang, Huang, & Lin , 1998, and Skinner, Holden, Holden, & Demorest, 1999).

Briefly, MAP T and C levels are set using ascending loudness judgments and counted thresholds for every electrode. The T levels are initially set at the loudness judgment of very soft to soft. The C levels are initially set at the loudness judgment of medium loud to loud. A detection threshold is then found at the lowest level that a sound percept is identified three times. The subject is then asked to correctly identify a set of two, three, four, or five pulse trains. If the subject is incorrect, the current level is then raised two levels at a time until the counted T is correctly identified three times. The T and C levels are modified by balancing the loudness two electrodes at a time. The electrodes are then swept from base to apex at T level, fifty percent, and C level and loudness is judged at each level. T level should be rated as very soft to soft. Fifty percent should be rated as medium-soft to medium. C level should be rated as medium loud to loud. The final MAP which is created after 6-8 weeks of programming and comprehensive aural rehabilitation was worn for at least three months in everyday life.

Procedures for recording ECAP

Using the NRT software (v3.0), the ECAP responses were recorded on all active electrodes from each patient. This software uses an artifact subtraction technique to separate the nerve's response from electrical artifact. This technique is described elsewhere in detail (Abbas et al., 1999; Brown, et al., 1990).

The NRT thresholds used in this study were previously measured as part of a larger research project examining the relation between NRT thresholds and cochlear implant recipients' speech recognition completed at Washington University. In this study, loudness judgments from first hearing to maximum acceptable loudness (MAL) were completed with the 80 Hz used to measure NRT thresholds. To begin searching for the NRT threshold the initial stimulating current level was set to 20 current levels below the subjects' MAL. If a measurable response could not be obtained, the current level was increased in two level steps until a response was seen. If no response was seen at the subject's MAL, an optimization series was run. This uses twelve combinations of amplifier gain, recording delay, and recording electrode. If no measurable response could be seen after the optimization series, the subject was asked if the level could be increased above the MAL. As long as the level was tolerable, it was increased one or two current levels at a time until an NRT threshold could be observed. If no observable response could be seen at maximum tolerable levels, the recording electrode, rate of stimulation, and pulse width were changed.

Four main criteria were used to determine an acceptable neural response. First, the N1-P2 amplitude was at least 20 µV measured from a high-resolution waveform. Second, there was no amplifier saturation in the waveforms stored in the D buffer. Third, the low-resolution waveforms were nearly parallel and did not cross before the first positive peak. Finally, the N1 latency was slightly later than the N1 latency of the waveforms before it.

Once a visual NRT (vNRT) threshold was recorded, a growth function was collected by recording a series of waveforms beginning at the highest level (MAL or maximum tolerable level) and decreasing in two current level steps until three waveforms were measured below the vNRT. After two additional recordings were made above the vNRT, the AGF could be calculated. To do this, the N1 and P2 peaks were marked on each of the waveforms and the software calculated the slope. From this, the Predicted Neural Response Threshold (tNRT) could be determined based on the data points entered into the software. The tNRT represents the intersection of the regression line with 0 µV on the y-axis.

Procedures for Creating NRT MAP

The Carolyn Brown and Cooper-Craddock methods discussed in the Introduction were used as the foundation for creating two procedures for making NRT based MAPs utilizing the

R126 software. Both of these NRT based MAPping procedures were modified by Cochlear Corporation to make them feasible for clinical programming. The first method to be discussed is what will be called the Carolyn Brown method (Brown et al, 2000; and Hughes et al 2000). In this procedure, behavioral Ts and Cs from the preferred MAP were entered on channel 11 into the Nucleus R126 (v2.1) programming software. Then, tNRTs were entered on electrodes 3, 7, 11, 17, and 22. These electrodes were chosen based on recommendations made by Cochlear Corporation. The T/C Offset was then determined according to the software. This function calculates the difference between the behavioral measures and NRT data entered. From this, the NRT based MAP was created from the information entered.

The second procedure for creating an NRT based MAP was based on recommendations made by Cooper and Craddock (Craddock et al, 2003). Compared to the Carolyn Brown method, this method included additional behavioral information and less information on objective measurements. The MAP T levels, MAP C levels, and tNRTs were entered on channels 3, 11, and 22. These electrodes were also chosen based on recommendations made by Cochlear Corporation. The T/C Offset was then determined by the software and the second NRT based MAP was generated. It should be noted that tNRT information was used in this study rather than vNRT because tNRT is a more objective measure. In addition, Brown et al, as well as Cooper and Craddock, used tNRT when creating their recommendations for NRT-based MAPs.

Results

NRT Recordings

ECAP thresholds using NRT could be recorded on 26 of the subjects. Three of the 29 subjects had no recordable NRT thresholds on any electrode. This was true even when stimulating at the subjects' maximum tolerable level. Of these three subjects, one was using the ACE 500 Hz coding strategy and two were using the ACE 900 Hz coding strategy.

From the information obtained from the other 26 subjects, NRT thresholds ranged from 129 to 232 current levels. Table 1 displays the mean NRT thresholds as well as the range for each electrode across all 26 subjects. In general, current levels needed to reach NRT threshold were higher through the middle of the array and lower at the ends. The largest range was seen on electrode 5. The smallest range was seen on electrodes 10 and 12.

Carolyn Brown MAP vs. Preferred MAP

Mean current T and C levels were calculated for the preferred MAPs and the NRT based MAPs. For the purposes of this paper, a current level difference of greater than 5 will be considered clinically significant. In general, the T levels using the Carolyn Brown method were within 5 levels of the preferred MAP T levels 43% of the time. In addition, the NRT based T levels were within 10 current levels of the preferred MAP T levels 86%of the time. The C levels using the Carolyn Brown method were within 5 levels of the preferred MAP C levels 53% of the time. C levels were within 10 levels of the preferred MAP 72% of the time.

In general, the NRT based T and C levels using this method were farthest away from preferred MAP T and C levels toward the basal and apical ends where no behavioral information was entered. In addition, the Carolyn Brown method tended to underestimate T and C levels as compared to the preferred MAP.

When separated into the different speech coding strategies and rates, the Carolyn Brown method estimated the preferred MAP best with the ACE 900/1200 Hz subjects. Figure 1 shows the average NRT based T and C levels were 3.63 (range was from 0 to 14) levels different from the SPEAK preferred levels. Figure 2 shows the ACE 900/1200 Hz strategy was an average of 3.16 (range was from 0 to 13) current levels different from the ACE 900/1200 Hz preferred levels. Finally, figure 3 shows the ACE 1800 Hz strategy, the T and C levels were an average of 7.11(range was from 0 to 22) levels off. Figures 1-3 show the NRT MAP levels using the Carolyn Brown method and preferred MAP levels for each strategy. With all strategies and rates combined, the Carolyn Brown NRT based method was an average of 4.90 current levels different than the preferred MAP levels. Figure 7 shows the combined strategy T and C levels for the Carolyn Brown method versus the preferred MAP T and C levels.

Examination of individual data revealed a wide variability between behavioral and NRT predicted MAP levels. Figures 9, 11, and 13 show examples of close approximations of the Carolyn Brown method for each speech coding strategy. Figures 10, 12, and 14 demonstrate poor approximations of this method for each coding strategy.

Cooper-Craddock MAP vs. Preferred MAP

In general, T levels using the Cooper-Craddock method were within 5 levels of the preferred MAP 70% of the time. In addition, T levels were within 10 current levels 89% of the time. The C levels using the Cooper-Craddock method were within 5 levels of the preferred MAP C-levels 73% of the time and within 10 levels 89% of the time.

The NRT based T and C levels using this method were farthest away from preferred MAP T and C levels in between electrodes 3 and 11 and between electrodes 11 and 22. These are the areas where less behavioral information was entered to create the NRT MAP. Also, this method tended to overestimate T and C levels at the basal end with the SPEAK coding strategy subjects. The Cooper-Craddock method is more likely to underestimate MAP levels at the apical end with the ACE 900/1200 Hz coding strategy as well.

When separated into different coding strategies and rates, the Cooper-Craddock method estimated the preferred MAP best with the ACE 1800 Hz coding strategy. On average the NRT based T and C levels were 2.58 (range was from 0 to 7) current levels different from the SPEAK preferred levels. With the ACE 900/1200 Hz subjects, the NRT based T and C levels were 2.53 (range was from 0 to 8) current levels off on average. Finally, with the ACE 1800 Hz coding strategy, the NRT MAP T and C levels were an average of 1.61 (range was from 0 to 4) current levels off from the preferred MAP. Figures 4-6 show the NRT MAP levels using the Cooper-Craddock method and preferred MAP levels for each strategy. With all strategies and rates combined, the Cooper-Craddock NRT based method was an average of 1.78 current levels different than the preferred MAP levels. Figure 8 shows the combined strategy T and C levels for the Cooper-Craddock method versus the preferred MAP T and C levels.

As with the Carolyn Brown method, individual data show a wide variability between behavioral and NRT predicted MAP levels. Figures 15, 17,and 19 show examples of close approximations of the Cooper-Craddock method for each speech coding strategy. Figures 16, 18, and 20 demonstrate poor approximations of this method for each coding strategy.

Discussion

Analysis of the data showed that there were differences between the two methods used. The mean data showed that the Carolyn Brown NRT based method T and C levels were within five current levels 43% and 53% of the time respectively. The Cooper-Craddock NRT based T and C levels were within five current levels 70% and 73% of the time respectively. The fact that the Cooper-Craddock NRT MAPs approximate behavioral MAPs better than the Carolyn Brown method can be explained by a greater amount of behavioral information being entered into the Cooper-Craddock NRT MAP. The behavioral MAP information used in the present study was collected after the implant had been worn and fine tuned for a minimum of three months. These findings may be different if T and C levels were not carefully measured and the MAPs were not fine tuned.

Rate seemed to be more important when using the Carolyn Brown NRT MAP method rather than the Cooper-Craddock method. The differences in the ability to match the preferred MAP T and C levels could be explained by the fact that Carolyn Brown only used SPEAK MAPs when creating her method for NRT MAPs. The ACE 1800 Hz MAP was the farthest off from the behavioral MAP for the Carolyn Brown method. This could be because it is such a faster rate than the SPEAK MAP and therefore there is greater temporal integration. However, the ACE 900/1200 Hz NRT MAPs are a closer approximation to the behavioral MAPs than the SPEAK MAPs. At this time, the experimenters can find no explanation for this. Cooper and Craddock do not specify which strategy and rate they used to create their NRT MAPs. It is feasible that if Cooper-Craddock used different strategies and rates in their study, this could be the reason the NRT based MAP levels were closer to the preferred MAP levels.

Our findings differ from the findings of Craddock et al. (2003). They reported that T and C levels derived from NRT based MAPs were in close agreement with SPEAK behavioral MAP levels. Our findings differ in that the Carolyn Brown method most closely estimated the ACE 900/1200 Hz MAPs. They also found that T levels in NRT based MAPs were in close agreement with ACE strategy T levels. NRT based C levels tended to overestimate behavioral C levels. In the present study we found that this method tended to underestimate T and C levels with all strategies. The differences between the present study and the Craddock study cannot be explained.

Examination of individual data revealed a considerable amount of variability. Therefore, caution should be taken when using the group mean data for creating an individual's NRT based MAP. When using the Carolyn Brown method, it was reported that the NRT based T and C levels were within five current levels of the preferred MAP levels 43% and 53% of the time respectively. Consequently, 57% of the time, the T levels could be greater than five levels different. In addition, the C levels could be greater than five levels different 47% of the time when using the Carolyn Brown method. If the Cooper-Craddock method were used, the T and C levels could be off by greater than five current levels 30% and 27% of the time respectively. More research needs to be done on why this individual variability exists.

It should be noted that the results of the present study may be different if a different set of electrodes were chosen to enter behavioral and tNRT information for the two methods used. In addition, the amount of time after implantation and how the behavioral information is collected is very important. Carolyn Brown, Cooper-Craddock, and the present study all reported that behavioral Ts and Cs were collected at least three months post-implantation. Carolyn Brown and Cooper-Craddock do not discuss how the behavioral MAP T and C levels were set.

Conclusions

NRT thresholds can be used in conjunction with limited behavioral data for accurate programming of cochlear implants. It was found that the more behavioral information that can be included with the NRT levels, the closer the MAP will be to the preferred MAP for that subject. In addition, well-adjusted T and C levels are needed to create an optimal MAP and these cannot be achieved at the initial stimulation. Since the NRT based MAP levels can be significantly different from preferred MAP data, additional behavioral information should be obtained quickly after creating the initial MAP. The NRT MAP should be swept and balanced, and soundfield thresholds should be obtained to ensure that the levels do not over- or underestimate the behavioral dynamic range. Caution should also be taken when creating an NRT MAP depending on which speech coding strategy and rate are used.

Table 1. Mean tNRT and range on each electrode.

	Mean tNRT	MIN	MAX
22	168	135	208
21	168	135	197
20	171	149	197
19	174	138	207
18	175	137	210
17	175	145	201
16	178	140	213
15	177	129	199
14	178	153	199
13	179	156	209
12	182	164	205
11	182	159	203
10	184	164	205
9	181	156	205
8	181	157	208
7	178	156	210
6	173	153	201
5	173	150	232
4	163	138	192
3	166	144	195

Figure 1. Behavioral MAP T and C levels (circles) and Carolyn Brown NRT based MAP T andC levels (squares) for subjects using the SPEAK speech processing strategy.

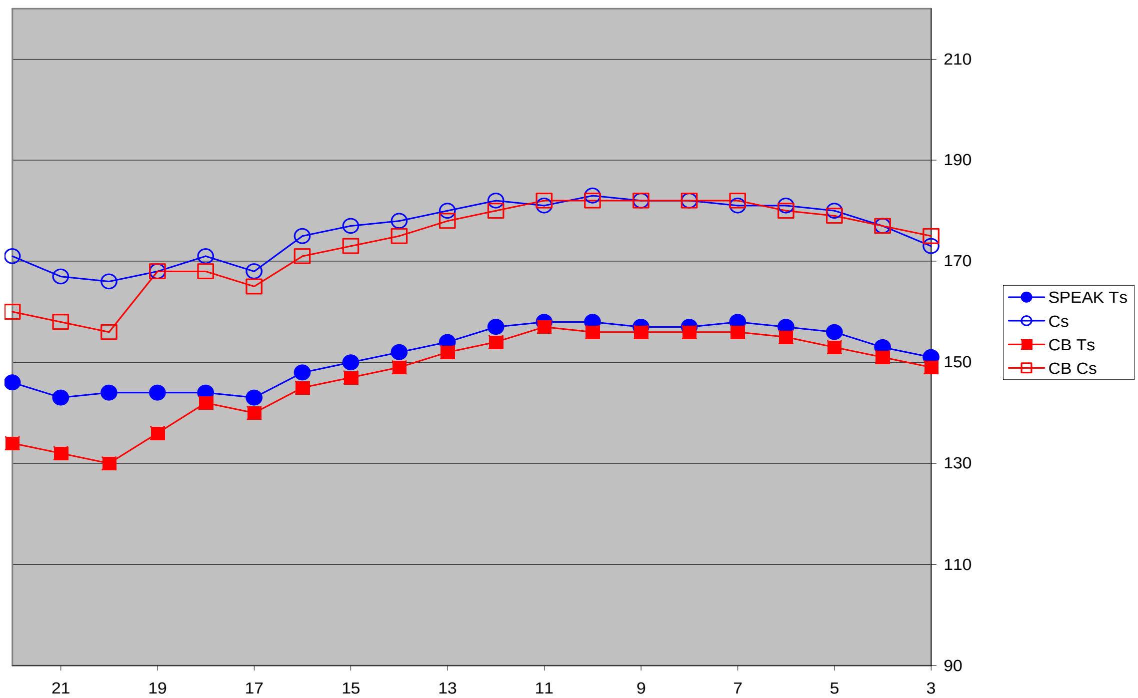


Figure 2. Behavioral MAP T and C levels (circles) and Carolyn Brown NRT based MAP T and C levels (squares) for subjects using the ACE 900/1200 Hz speech coding strategy.

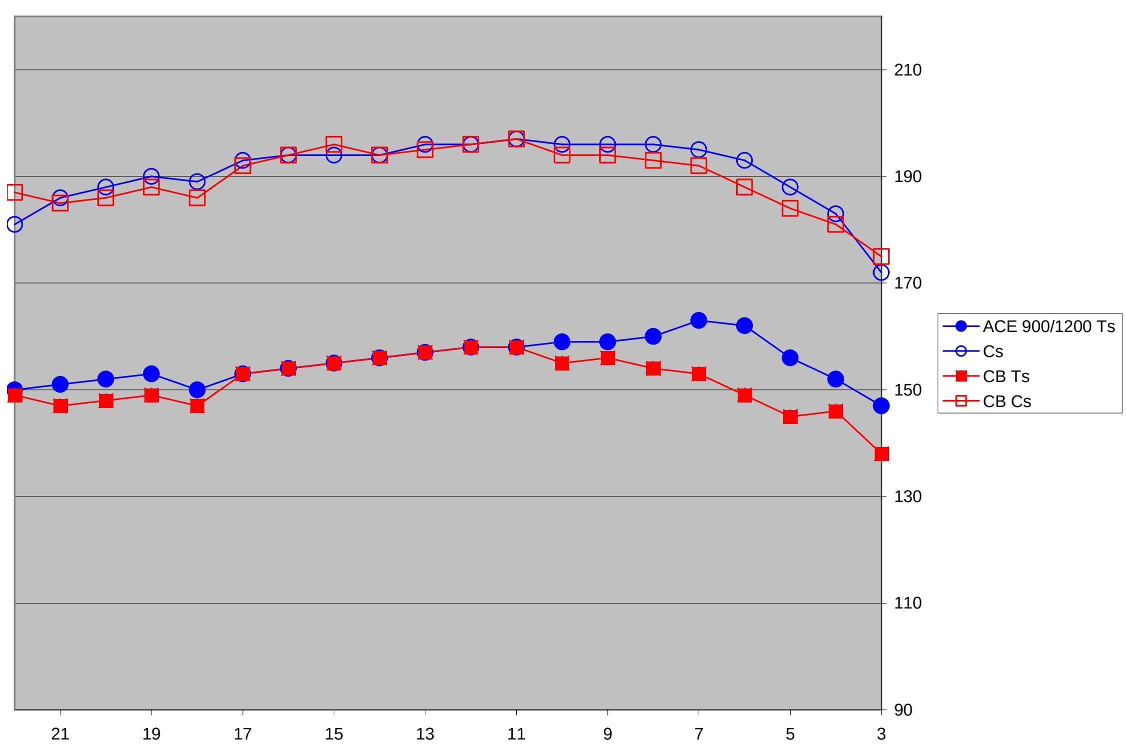


Figure 3. Behavioral MAP T and C levels (circles) and Carolyn Brown NRT based MAP T and C levels (squares) for subjects using the ACE 1800 Hz MAP speech coding strategy.

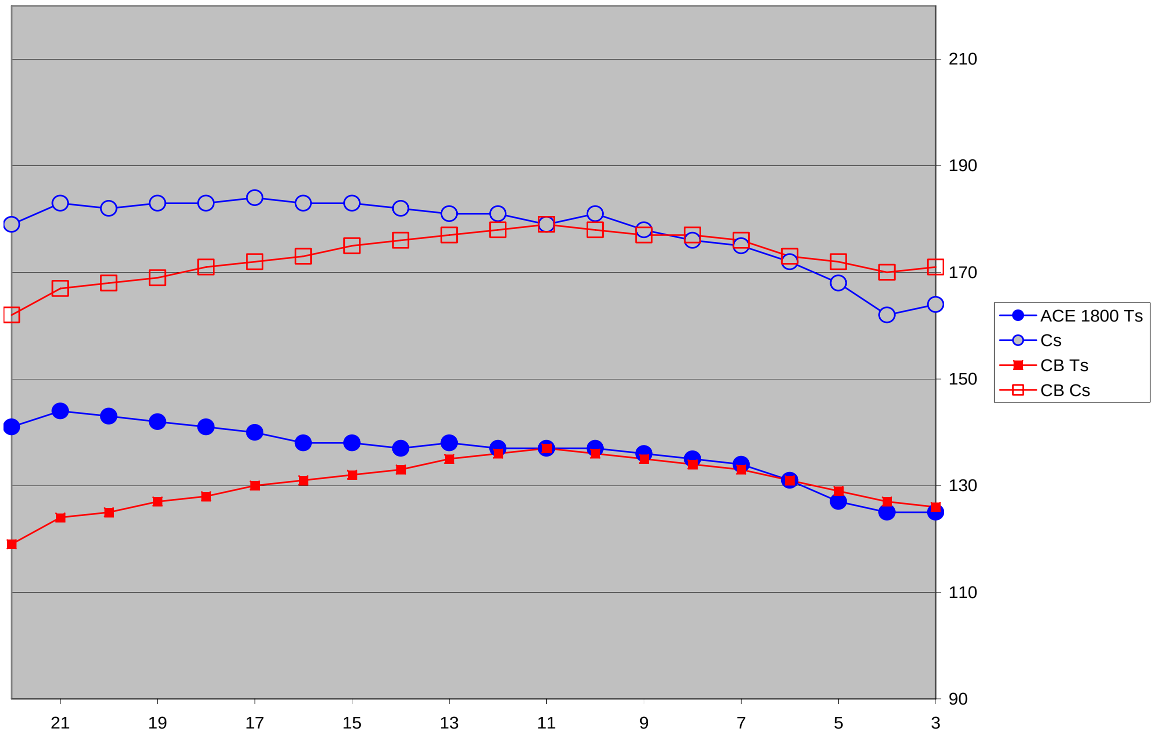


Figure 4. Behavioral MAP T and C levels (circles) and Cooper-Craddock NRT based MAP T and C levels (squares) for subjects using the SPEAK speech coding strategy.

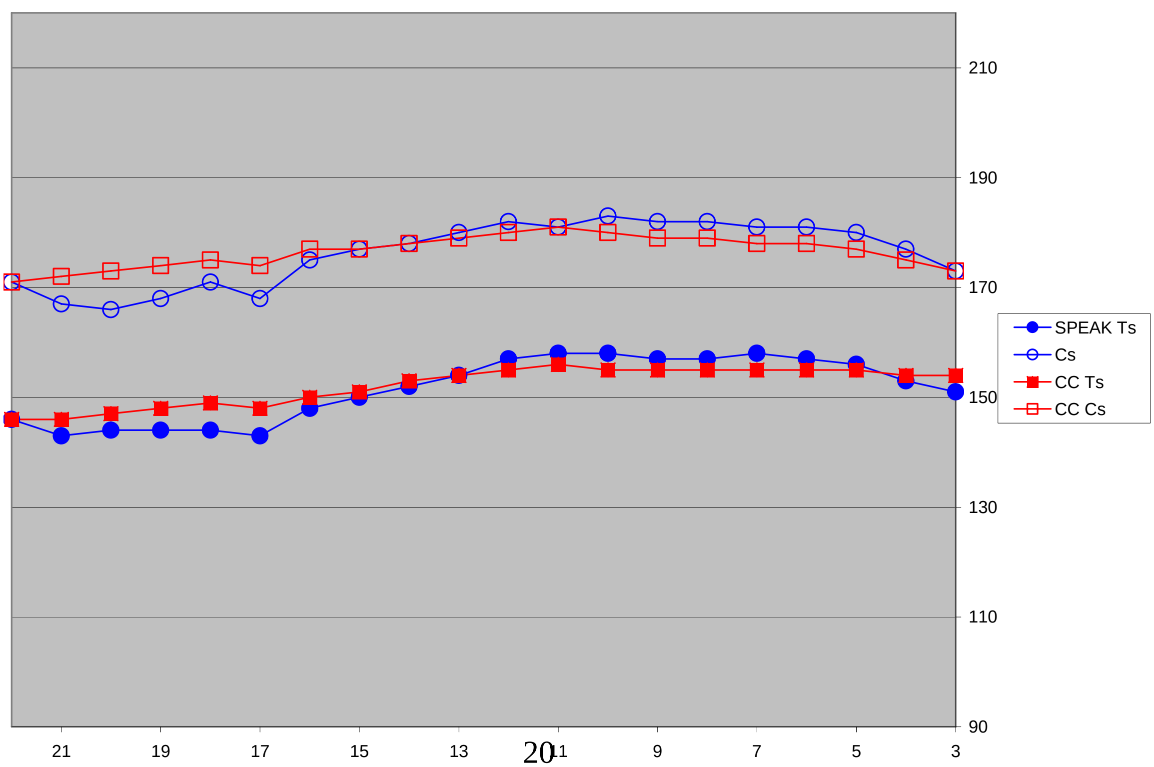


Figure 5. Behavioral MAP T and C levels (circles) and Cooper-Craddock NRT based MAP T and C levels (squares) for subjects using the ACE 900/1200 Hz speech coding strategy.

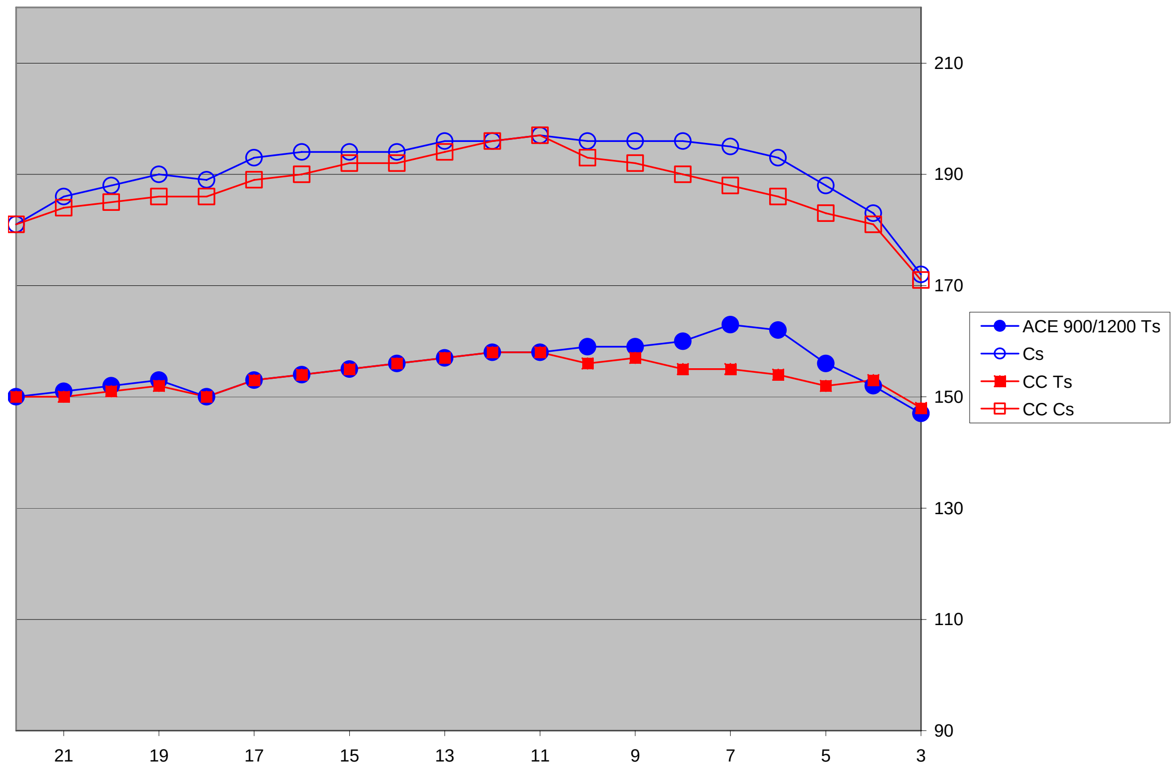
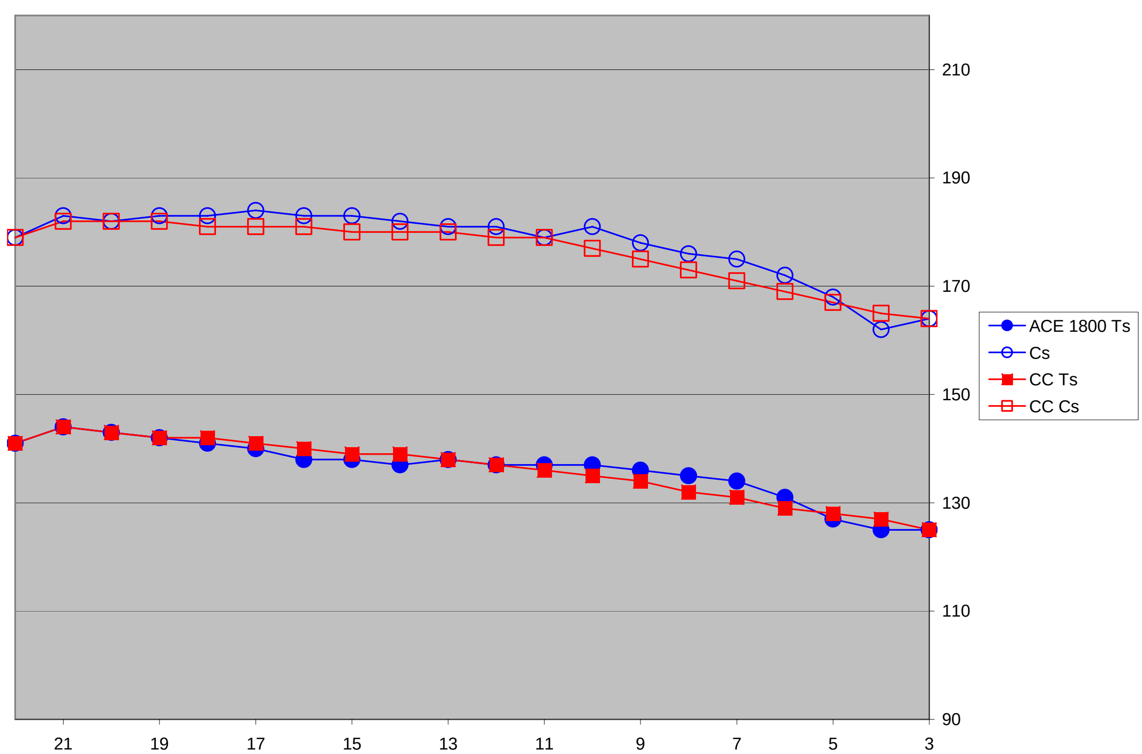


Figure 6. Behavioral MAP T and C levels (circles) and Cooper-Craddock NRT based MAP T and C levels (squares) for subjects using theACE 1800 Hz speech coding strategy.



Firg7. Behavioral MAP T and C levels (circles) and Carolyn Brown NRT Based MAP T and C levels (squares) for all speech coding strategies combined.

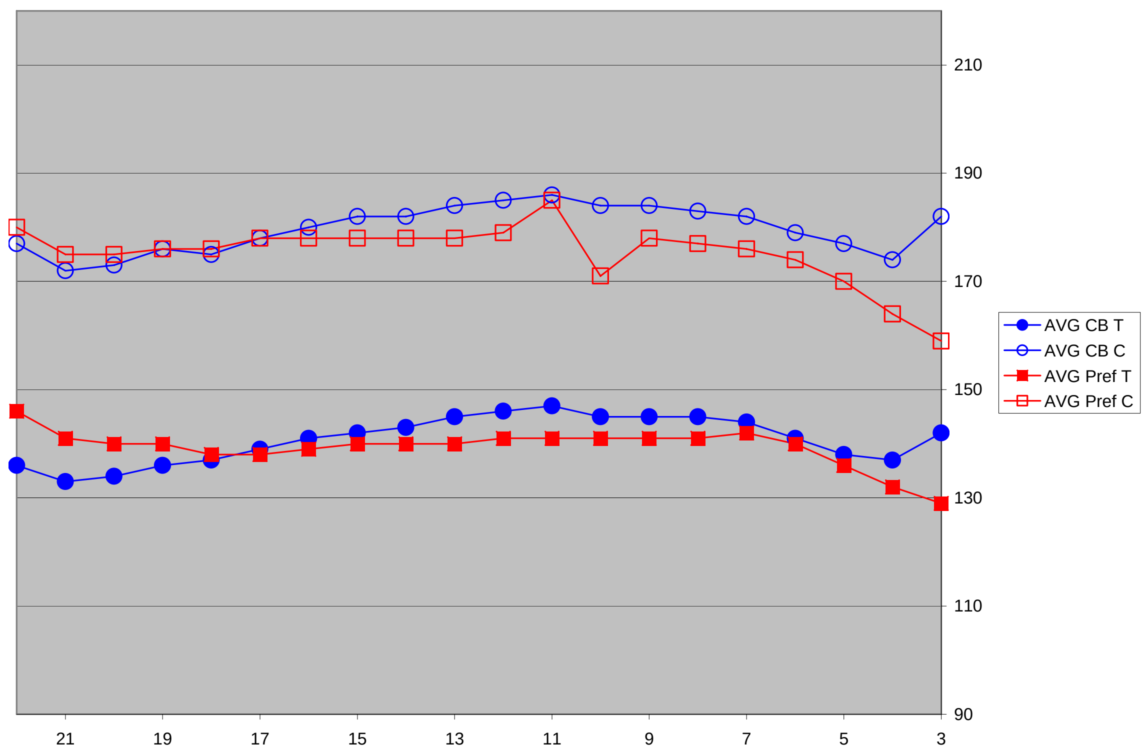


Fig 8. Behavioral MAP T and C levels (circles) and Cooper-Craddock NRT Based MAP T and C levels (squares) for all speech coding strategies combined.

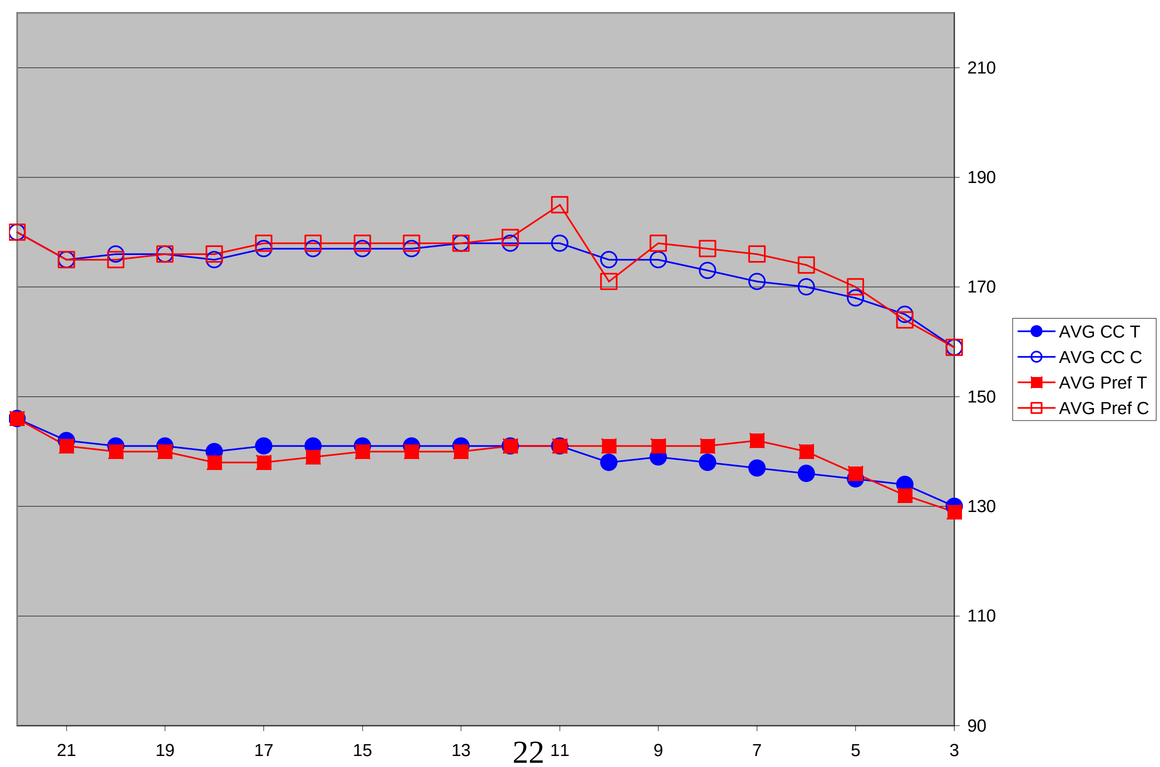


Figure 9. Behavioral MAP T and C levels and Carolyn Brown NRT based MAP T and C levels for one subject using the SPEAK strategy.

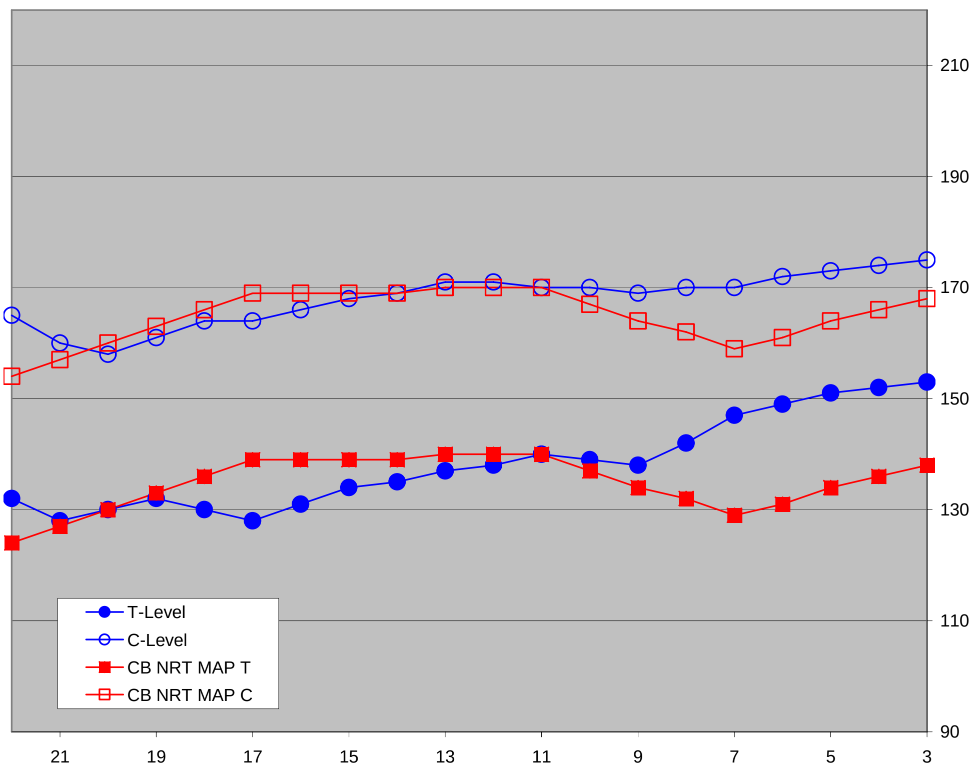


Fig
ure 10. Behavioral MAP T and C levels and Carolyn Brown NRT based MAP T and C levels for one subject using the SPEAK strategy.

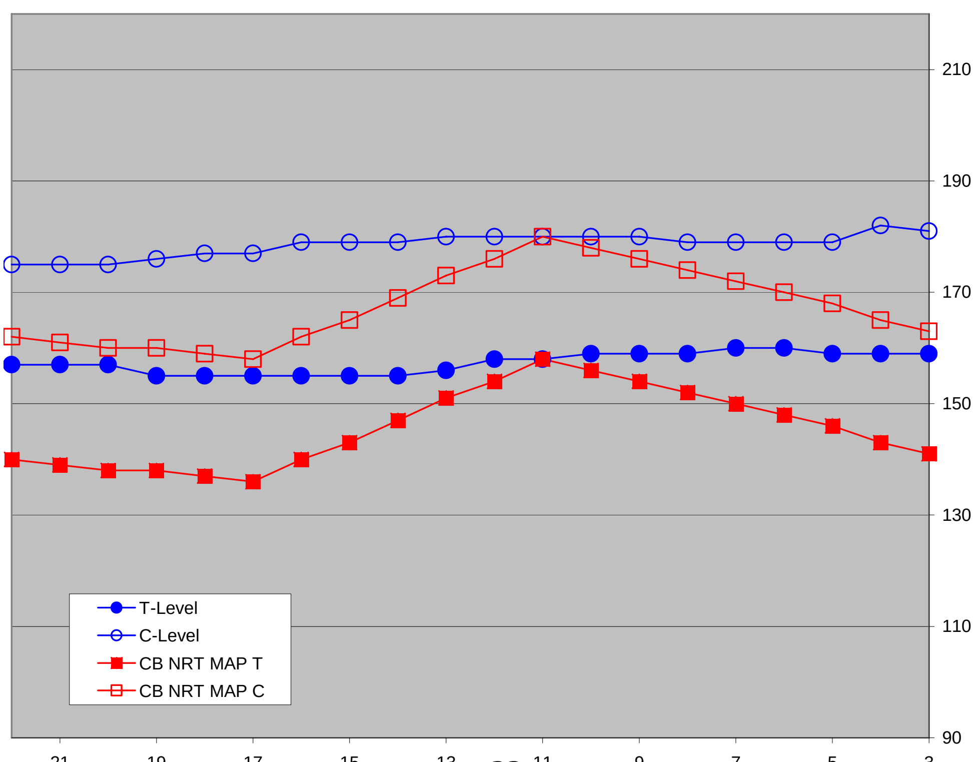


Figure 11. Behavioral MAP T and C levels and Carolyn Brown NRT based MAP T and C levels for one subject using the ACE 900/1200 Hz strategy.

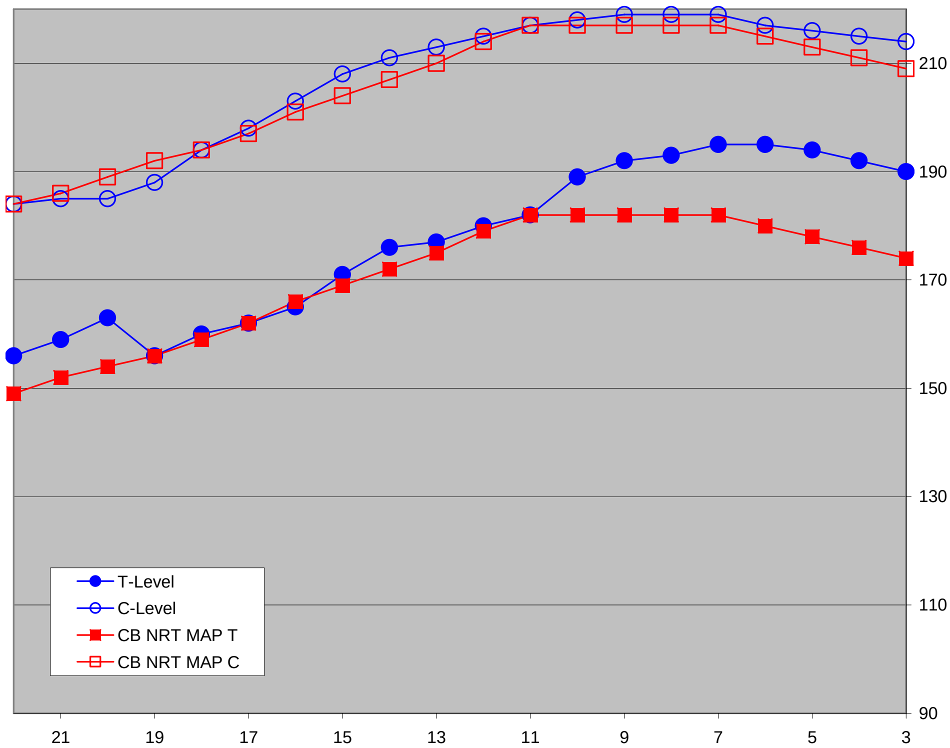


Figure 12. Behavioral MAP T and C levels and Carolyn Brown NRT based MAP T and C levels for one subject using the ACE 900/1200 Hz strategy.

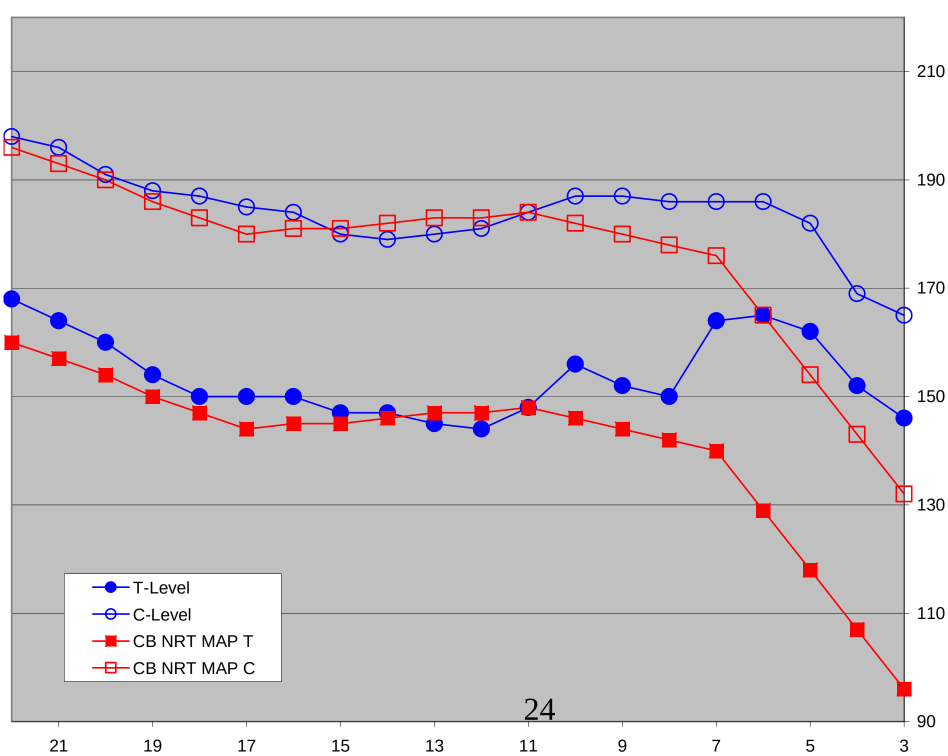


Figure 13. Behavioral MAP T and C levels and Carolyn Brown NRT based MAP T and C levels for one subject using the ACE 1800 Hz strategy.

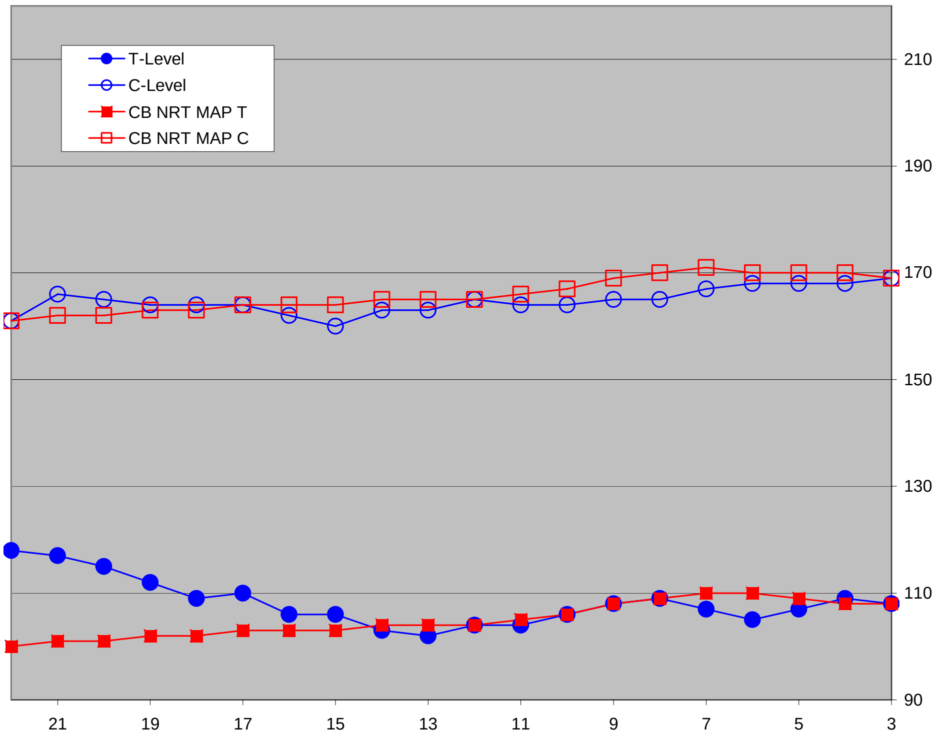


Figure 14. Behavioral MAP T and C levels and Carolyn Brown NRT based MAP T and C levels for one subject using the ACE 1800 Hz strategy.

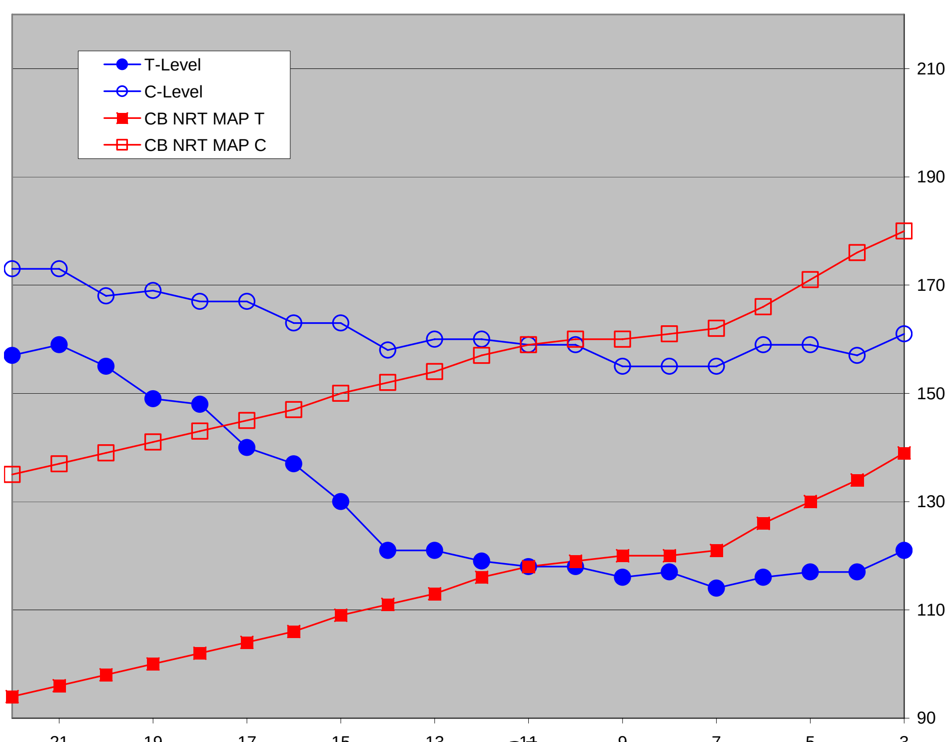


Figure 15. Behavioral MAP T and C levels and Cooper-Craddock NRT based MAP T and C levels for one subject using the SPEAK strategy.

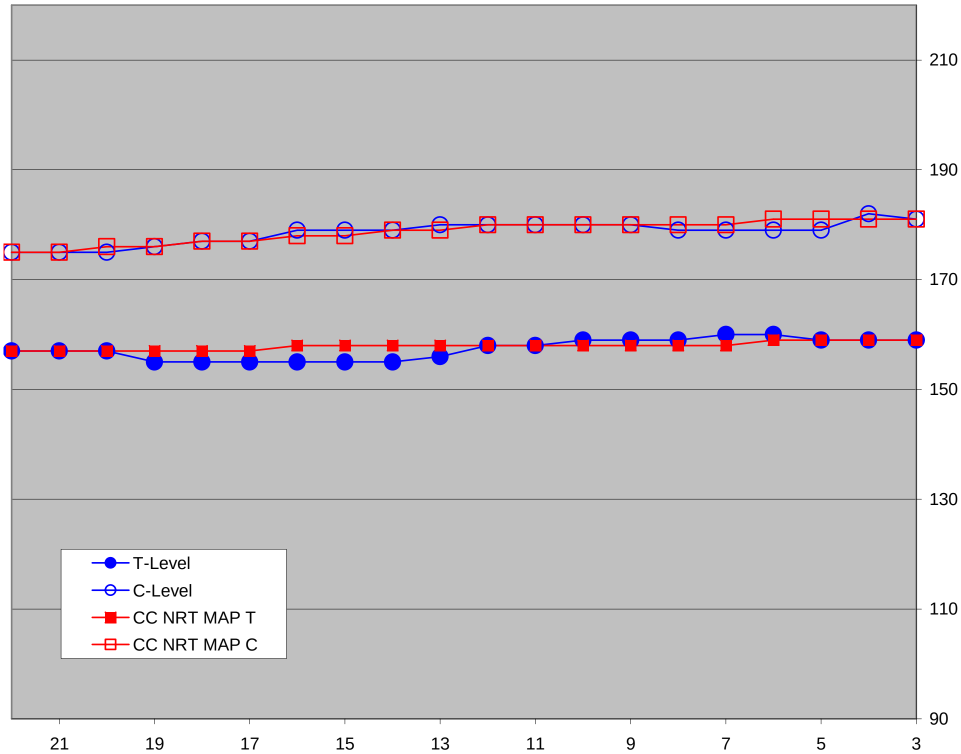


Figure 16. Behavioral MAP T and C levels and Cooper-Craddock NRT based MAP T and C levels for one subject using the SPEAK strategy.

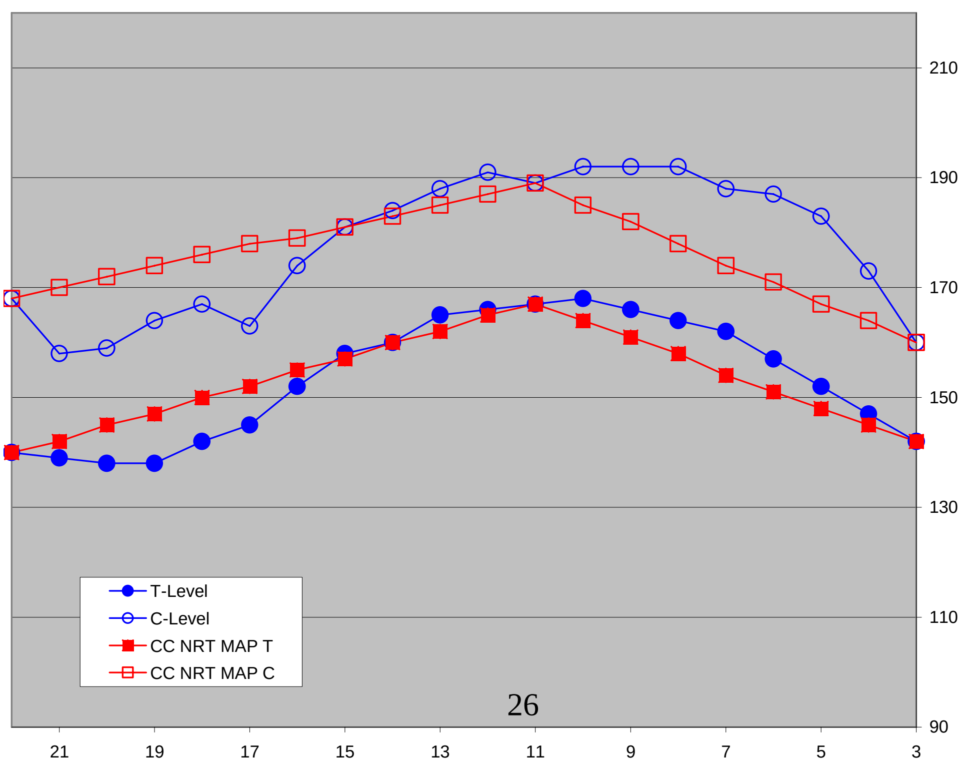


Figure 17. Behavioral MAP T and C levels and Cooper-Craddock NRT based MAP T and C levels for one subject using the ACE 900/1200 Hz strategy.

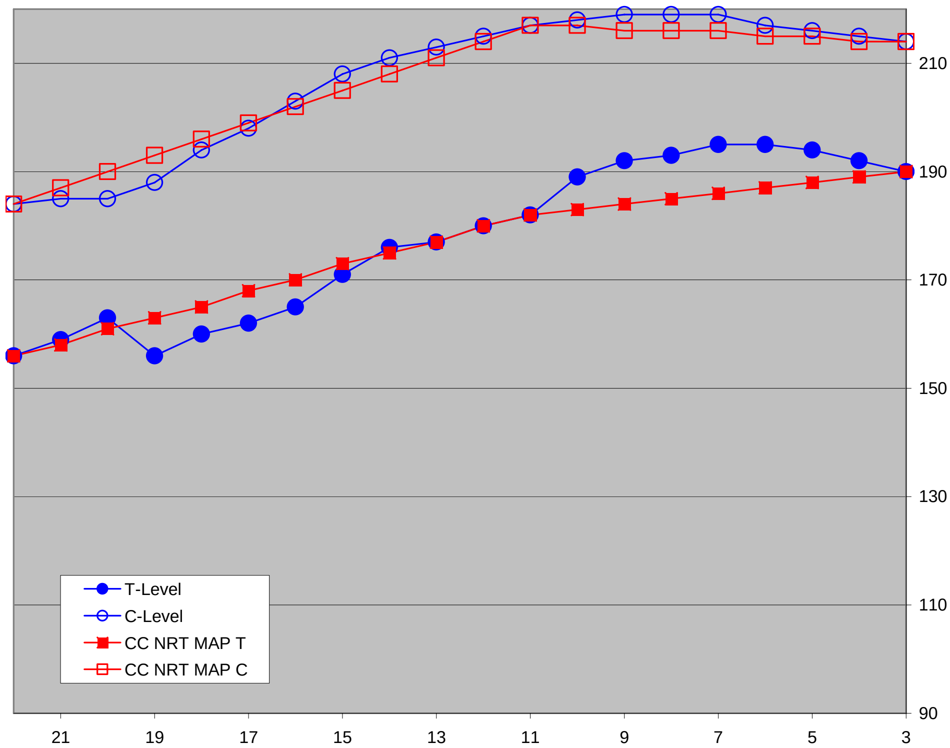


Figure 18. Behavioral MAP T and C levels and Cooper-Craddock NRT based MAP T and C levels for one subject using the ACE 900/1200 Hz strategy.

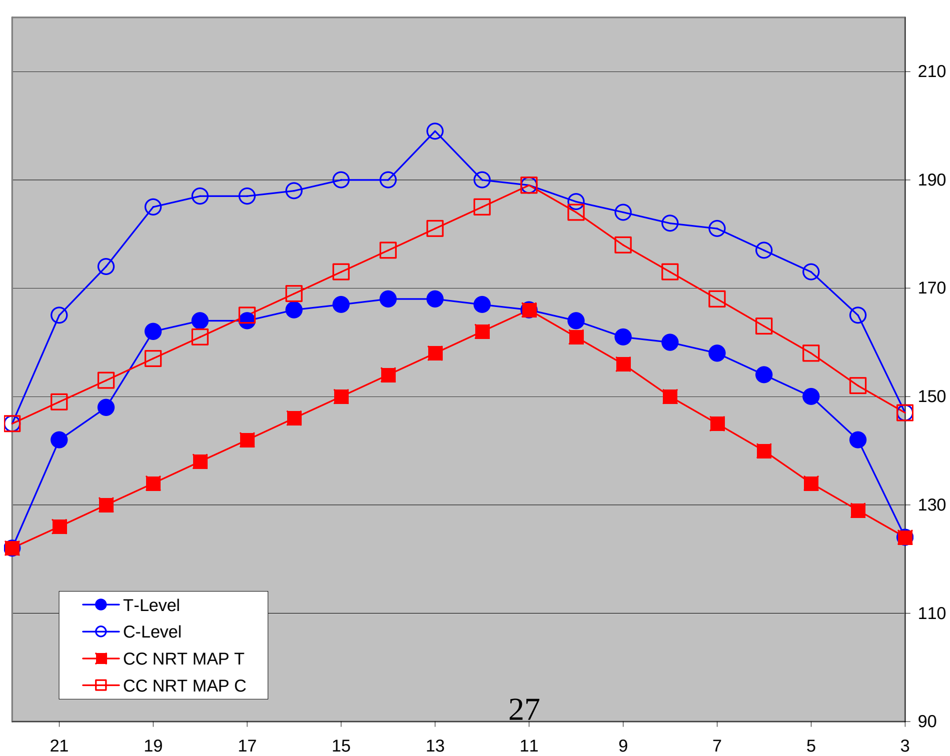


Figure 19. Behavioral MAP T and C levels and Cooper-Craddock NRT based MAP T and C levels for one subject using the ACE 1800 Hz strategy.

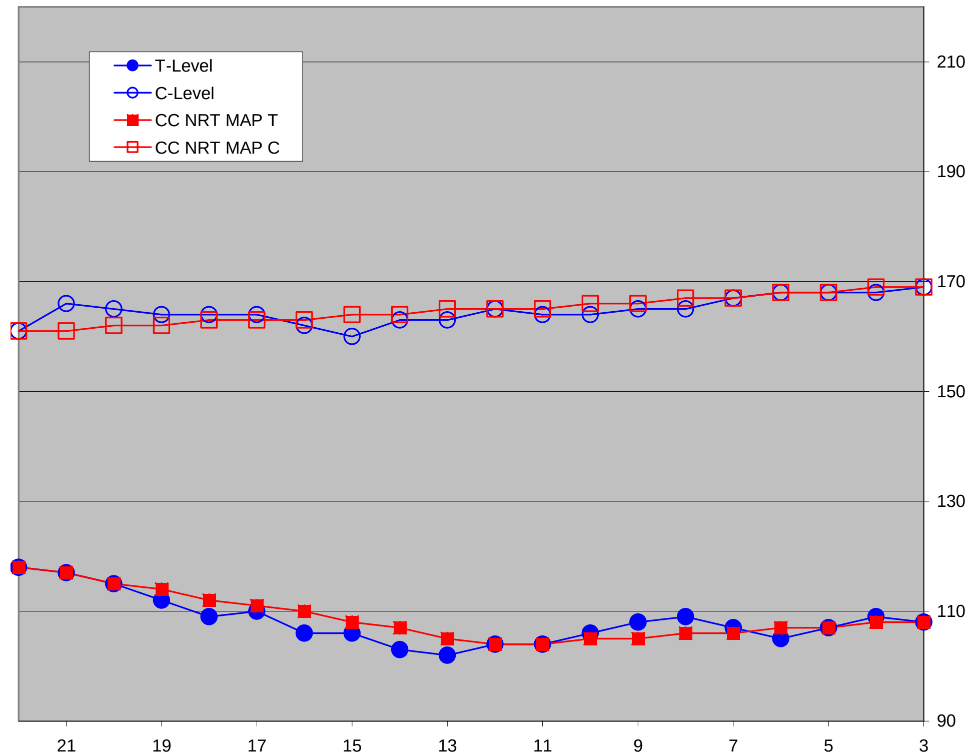
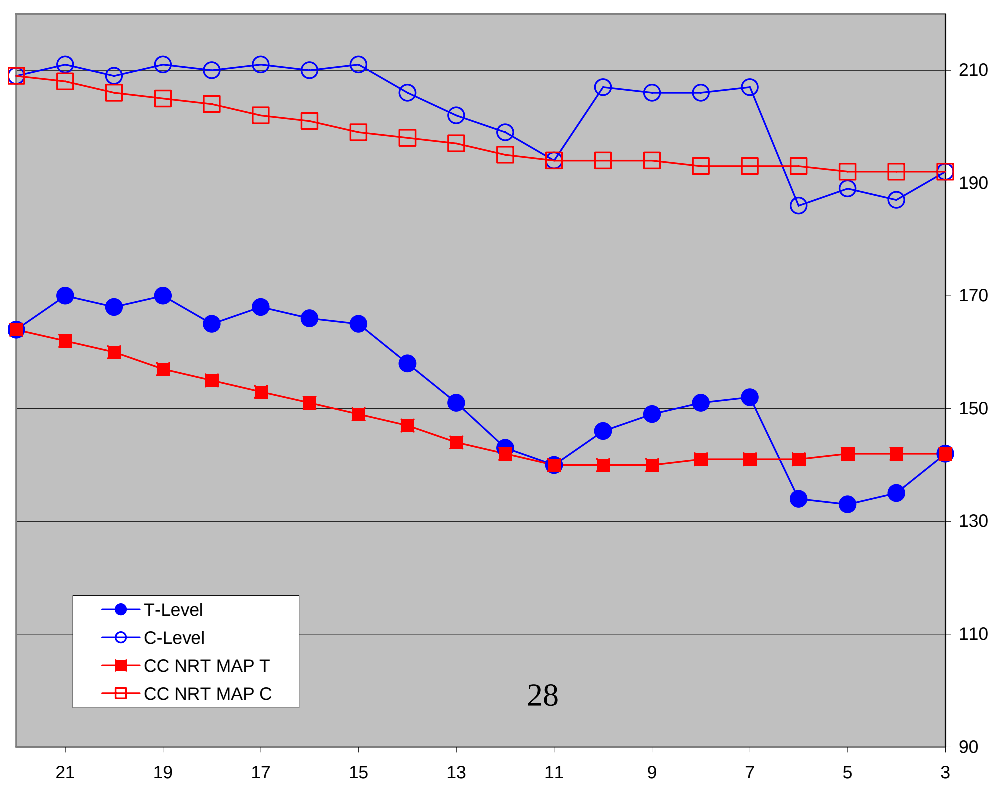


Figure 20. Behavioral MAP T and C levels and Cooper-Craddock NRT based MAP T and C levels for one subject using the ACE 1800 Hz strategy.



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