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Compatibility of a magnetic position tracker with a cochlear implant system

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Abstract

Objectives: Aim of this study was to reveal possible interspersions of a magnetic position tracking device into a cochlear implant system, which could lead to harmful signals on the implanted electrode.

Design: Signals at the output of the speech processor's compression stage and at the implant's electrode were recorded and analyzed for unwanted distortion or corrupted pulses related to the presence of the magnetic tracking device.

Results: No systematic impact of a Polhemus Liberty Latus magnetic tracking system on the output signals of an Advanced Bionics HiRes90k cochlear implant and Platinum Series speech processor was found.

Conclusions: The results suggest no objections for using the Polhemus Liberty Latus magnetic position tracker with the Advanced Bionics Platinum series speech processor and HiRes90k cochlear implant in research, e.g. on spatial hearing. This result is likely transferable to other cochlear implants because (i) all manufacturers adhere to equally high electro-magnetic interference standards and (ii) electro-magnetic signals used by the transmission links of current cochlear implants and trackers differ in frequency by roughly two decades, making interference unlikely.

Keywords

magnetic tracker; position tracking; cochlear implant; electro-magnetic compatibility (EMC); spatial hearing

Introduction

Accurate electronic tracking of positions in 3D-space has allowed researchers to address questions on the development of the spatial senses, audition, vision and proprioception, and their interaction with innovative experiments. Spatial hearing research has a long history of using position tracking systems either to gain feedback from the subject in localization experiments (Brungart et. al 1999) or to interactively render virtual acoustic environments (Horbach et. al 1999). Optical tracking systems evaluate camera images while magnetic trackers evaluate changes in a magnetic field to determine the position of small marker devices. Magnetic trackers are frequently used in hearing research because of their high speed and low cost.

Spatial hearing and its development is the focus of current research with hearing impaired subjects and those with cochlear implants (CIs) (Seeber et al., 2008). It is unclear if the magnetic field of the position tracker interferes with the CI, producing unwanted or even dangerous output signals at the implanted electrodes. Magnetic interspersions into the CI can occur through the electro-dynamic microphone or the magnetic transmission link between speech processor and implanted cochlear stimulator. A series of measurements was undertaken to assure that CI-subjects would not be harmed by the tracker, a prime objective of ethically correct research. The measurements demonstrate that a magnetic tracker did not affect the CI-signal through the microphone or the transmission link.

Materials and Methods

Cochlear implant system

Measurements were performed using an Advanced Bionics Platinum series speech processor (Advanced Bionics: Sylmar, California, USA) connected to a HiRes90k cochlear implant (Kessler 1999). This speech processor is a body worn device which connects to the implant using a transcutaneous magnetic link; the link is secured by a handshake protocol. A headpiece contains the magnetic coil for the link and an electro-dynamic microphone. The speech processor also allows for the input of sounds through a direct input (AUX).

The Advanced Bionics research interface was used to control and power the CI-system and record its output: 1) The speech processor was connected to a personal computer (PC) via the programming interface, 2) The induction coil of the speech processor was either connected to an implant housed in a box (Bionic Ear Simulator, Figure 1), or to a circuit board with a HiRes90k implant connected to a resistor network from which the output of each electrode could be recorded from (electrode breakout board, not shown). The Bionic Ear Simulator was used for the measurement of interspersions into the electro-dynamic microphone while the electrode breakout board was used for the measurements involving the transmission link. The programming interface also allowed routing of internal signals of the speech processor to an output, e.g. the analog signal before and after the compression stage. Signal processing parameters of the CI, e.g. pulse rate, height and width, were programmed with research software on the PC.

Magnetic tracking system

The susceptibility of the CI to magnetic interference was evaluated with a Polhemus Liberty Latus magnetic tracking system (Polhemus: Colchester, Vermont, USA). The system calculates the position and orientation of small, wireless senders (markers) which emit alternating magnetic fields. The magnetic field is sensed by up to twelve receivers connected to a central processing unit. The orientation and position of the markers is calculated from the magnetic field in a predefined global co-ordinate system.

The orientation of the marker relative to the CI is defined in a marker-specific Cartesian coordinate system. It is given as the plane of the marker's coordinate system, which during the measurement is parallel to the flat side of the CI's headpiece on which the marker was laying on. Three basis orientations result which are named according to the axes which span the parallel plane to the headpiece (Figure 1): "xy", "xz" and "yz".

Measurement method and equipment

Magnetic interspersions into CI systems—The electro-dynamic microphone and the transmission link appear most susceptible for interspersions of magnetic fields into CI-systems because both house coils which are essential for their function. It is feared that the altering magnetic field of the markers could induce a voltage (electro-magnetic induction)

into these coils, affecting the signal at the implanted electrode. Other parts of the CI-system appear unlikely to be susceptible to magnetic fields as the signals are processed within the integrated processor chip. If the frequency of the magnetic field is within the audible range, any interspersed into the electrodynamic microphone would be audible. The frequencies used in the magnetic motion tracker are above this range, but they could be nonlinearly mixed with the actual acoustic input signal at any of the following signal processing stages in the speech processor. This can generate nonlinear distortion products in the audible range which would be further processed and delivered to the implant electrode. Coupling of a marker's magnetic field into the transmission link could cause alterations in the transmitted information between speech processor and implant. Because this information controls the parameters for pulse generation, corrupted information could alter pulse-amplitudes and/or pulse timing at the electrodes of the implant which could result in wrong percepts and harmful output signals on the implant electrode.

Interspersed into the electrodynamic microphone—To measure distortion caused by interspersed into the microphone, the output of the compressor of the CI-system was analyzed. The CI-system was set to use a dual automatic gain control (AGC) compressor. The compressed signal was routed to an output at the research interface from which it was recorded for 5 s duration using the analog inputs of a soundcard built into a PC (M-Audio Audiophile 2496, 16 bit, 44.1 kHz sampling rate). During the recording marker “4” of the Polhemus Liberty Latus system was laying on the headpiece of the implant either activated in one of the three basis orientations or switched-off. The marker was positioned directly on the headpiece about 1 cm alongside the microphone – closer than in practical use but without covering the microphone opening. The acoustic input signal was a sinusoid of either 1000 or 1010 Hz and was played from a custom-built loudspeaker placed at 1 m distance in a sound-treated room, creating a sound pressure level of 65 dB SPL at the microphone. The two slightly different frequencies were chosen to allow distinction of distortion products from measurement noise since frequency changes in the input signals cause systematic changes of the frequencies of the distortion products.

A second measurement tested if the marker magnetically induces a signal in the microphone that interferes nonlinearly with an audio signal at the AUX-input. The acoustic signal was fed directly into the AUX input with an amplitude of 1.18VRMS, while a marker was positioned on the CI's headpiece. The speech processor sums the signals of microphone and AUX-input in a 1:1 ratio before they reach the AGC. Distortion was measured from the output signal of the AGC for the activated marker positioned in the three basis orientations plus for the marker switched-off.

The degree of distortion was estimated from 5 s long recordings by calculating “total-harmonic distortion + noise” (THD+N) for each marker condition (off, on-xy, on-xz, on-yz). Recorded signals were filtered with a notch filter (4th order Butterworth band-stop, 50 Hz bandwidth symmetrically around the input frequency) and the level of the signal energy (in dB) was calculated before and after filtering. The difference between these levels gives an estimate of the total energy of the distortion products plus the noise relative to the signal level. Smaller values for THD+N correspond to less distortion and noise in the measured signal. A THD+N of 0 dB corresponds to an output signal dominated by distortion products and noise such that the presence of the input tone does not affect the overall level.

Interspersed into the transmission link—To test for tracker induced alterations in the pulses on the electrode, the implant system was set to output blocks of 200 ms biphasic pulses (rate: 2900 pulses-per-second (pps); pulse-width of one pulse phase: 10.8 μ s; pulse-height: 500 proprietary units) using the Advanced Bionics software. Pulses were recorded at the output of a mock electrode, consisting of an implant connected to a resistor network (4.7

k Ω). The recordings were done with the marker either switched-on or off and laying on the headpiece in one of the three basis orientations. A digital storage oscilloscope recorded the signal of CI channel 7 at a sampling rate of 2.5 Megasamples/s. Channel 7 was chosen arbitrarily since corrupted information in the transmission link should affect pulses on every electrode with equal probability. Twenty blocks with the marker off, and 22 blocks per basis orientation with the marker on were recorded. Gathered data were transmitted from the oscilloscope to a PC via network connection and further analyzed in Matlab.

Three parameters were calculated for every recorded pulse: pulse-height, defined as the difference between the maximum and minimum voltage of the biphasic pulse, pulse-width, the time between the pulse at 10% of its negative maximum and when the pulse falls below 10% of its positive maximum, and “interpulse-interval”, the time between the points where the voltage of two consecutive pulses reaches 10% of their respective negative maxima. The parameters were computed from the low-pass filtered pulse-blocks (2_{nd}-order Butterworth low-pass, corner-frequency 250 kHz) to reduce noise in the recording without altering the basic form of the pulses. Additionally, the number of pulses in every 200 ms block was counted to reveal possible dropouts due to the magnetic field.

Results

Interspersion into the electrodynamic microphone

The results for the THD+N measurements in Table 1 show neither systematic variation with the marker state and orientation nor with the used input or the frequency of the sinusoidal test tone. Most importantly, distortion does not increase with activation of the marker, which would be visible through systematically higher values for THD+N in the marker-on conditions. THD+N averaged across all conditions is -4.3 dB which illustrates the high distortion and low signal-to-noise ratio in the CI-system after the compression stage even without any interferers present.

An evaluation of the spectra of the recorded signals also shows that no distortion products were generated. Figure 3 depicts the measured spectra at the output of the compressor stage with the marker switched-off and activated laying on the headpiece in orientation xy. Results for this condition are also representative for all other measurements. Distortion products resulting from nonlinear mixing of marker induced field and acoustic microphone input would be strongest at the 2_{nd} and 3_{rd} order distortion frequencies (indicated by arrows). At none of those frequencies distortion products appear in the spectrum with activation of the marker. Thus no influence of the marker's magnetic field on the CI was observed.

Interspersion into the transmission link

The number of pulses per recording interval for each condition varied non-systematically with marker state and orientation. On average, a recorded block contained 584.4 ± 1 pulses, which is slightly more than the expected 580 pulses with the pulse-rate of 2900 pps and the block-length of 200 ms. A Kruskal-Wallis test to check for interaction between number-of-pulses per block and marker condition proved to be non-significant on a 5%-level.

Measured interpulse-interval and pulse-width are shown in the top and middle panel of Figure 2, respectively. Again, no systematic differences between conditions were observed. Average results for interpulse-interval are in accordance with the expected value of $344.8 \mu\text{s}$ (set pulse rate of 2900 pps). In no condition did dropouts or insertions of pulses occur since the extreme values for interpulse-intervals differ only by a maximum of $2 \mu\text{s}$, well below the duration of a single pulse. In conclusion, no influence of the marker's magnetic field on interpulse-intervals was observed. Measured pulse-width is highly constant across all

conditions. Observed maximum deviations from the average pulse-width are smaller than the minimum step-size for setting the pulse-width in the implant (1.8 μ s, indicated by dotted lines in the middle panel of Figure 2). We conclude that the presence of the magnetic field had no influence on the width of the stimulation pulses. Measured pulse-heights are given in the bottom panel of Figure 2. Statistical testing for interaction between average pulse-height per block and marker condition proved to be non-significant on a 5%- level (Kruskal-Wallis test). Extreme values exceeded the minimum possible amplitude step permitted by the implant (dotted lines) similarly in all conditions. Additionally, since bit-errors in the transmission link would not just affect the least significant bit, this result cannot be attributed to interference in the transmission link caused by the markers.

Discussion and Conclusions

Our measurements showed no systematic interference between an Advanced Bionics CI-system (Platinum Series speech processor and HiRes90K implant) and a magnetic tracking device (Polhemus Liberty Latus). The presence of the magnetic field of the marker of the tracking system did not result in additional distortion at the output of the compressor stage in the speech processor. This suggests that interspersions into the electro-dynamic microphone of the implant was negligible, likely for two reasons: a) the induced signals from the tracking markers are small compared to the acoustic input signals, b) the input filter of the implant blocked the frequencies emitted by the marker since they are above the audible frequency range. The result likely applies to other processor types and manufacturers as microphones are generally similar. In the evaluated system the microphone is placed directly below the cover of the headpiece. In behind-the-ear (BTE) type processors the microphone might be placed further inside the housing, increasing the distance to the marker and thus the resilience against magnetic interference.

The analysis of the pulses at the implant electrode showed no disruption by the presence of the marker near the transmission link. This suggests that the magnetic field of the marker did not interfere with the transmitted information between speech processor and implant. Any interference would have been visible in our measurements through systematic alterations in interpulse-intervals, pulse-widths or pulse-heights between marker-on and marker-off conditions. These results support the success of safety precautions taken by CI-manufacturers: The magnetic coupling in the transmission link between the speech processor and the implant is very high which leads to a high resistance against outside magnetic fields. The data transmission is further secured by a handshake-protocol, causing the CI to switch off if handshake phrases are distorted. CI-manufacturers test their devices to withstand electro-magnetic fields which are likely stronger than those emitted by a position tracker (e.g. mobile phones, metal detectors or MRI). The magnetic tracker is CE-marked which confirms that its emitted magnetic field strength is within standardized limits.

In conclusion, the measurements suggest that there are no restrictions to using the Polhemus Liberty Latus position tracker along with an Advanced Bionics Platinum series speech processor and a HiRes90k CI in laboratory environments for psychoacoustic research. Although not impossible, it is unlikely that outcomes would be different for other CIs or motion trackers due to the following reasons: 1) Similar standards regarding electro-magnetic interference are followed by all manufacturers irrespective of the device type (i.e. body-worn or behind-the-ear processors). Standardized tests assure compliance with electro-magnetic interference limits for all manufacturers (Tognola et al. 2007). 2) Although interference could occur if electro-magnetic fields of CI and tracker were in the same frequency range, this is unlikely to happen since current CIs and tracking markers operate at frequencies orders of magnitude apart. The tracking markers operate with frequencies lower than 40 kHz (Polhemus Fasttrack (1993): 8-14 kHz, Polhemus Liberty Latus: 22-39 kHz)

whereas the transmission links of typical implants use frequencies in the MHz range (Med-El C40/C40+: 12MHz; Advanced Bionics Clarion Implant: 49 MHz and 10.7 MHz; Cochlear Nucleus 24 ESPrit and ESPrit 22: 5 MHz and 2.5 MHz, respectively). 3) The use of different position trackers emitting other types of electro-magnetic fields (e.g. pulsatile systems) should not change the outcome as long as the maximum field strength of such systems does not exceed those in our measurements. In the tested system the markers emit the magnetic field while in other systems, e.g. the Polhemus Fasttrack, the field is emitted from static senders. While we tested for the marker in closest distance to the CI, the static senders are commonly placed further from the CI which should reduce the field strength at the CI, making them potentially safer.

Précise

Tracking of positions in space allows innovative and intuitive experiments and magnetic trackers have become increasingly popular for research on spatial hearing. Since cochlear implant (CI) systems are susceptible to magnetic interspersions, this article aims to quantify the impact of the Polhemus Liberty Latus tracking system on an Advanced Bionics HiRes 90k CI with Platinum Series speech processor. The intention was to reveal alterations in the output signals of the CI-system due to interspersions of the magnetic tracker in order to prevent corrupted or even harmful signals reaching the CI-user. No such systematic alterations were found in the measurements.

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Figure 1.

Definition of orientations of the tracking marker when positioned on the CI's headpiece. Top left: Headpiece on Bionic Ear Simulator alone; other pictures illustrate orientation of marker named as in inlay. The displayed CII Bionic Ear was only used for the microphone measurements; the circuit board for recording the electrode signals is not depicted.

Figure 2.

Differences in measured interpulse-interval (top panel), pulse-width (middle panel) and pulse-height (bottom panel) depending on the state and basis orientation of a magnetic tracking marker laying on the CI-system's headpiece during measurements. Boxes show medians and quartile ranges, extreme values are displayed as error bars. Dotted lines (middle and bottom panel) show the size of the smallest possible change in pulse-width and height permitted by the CI-system.

Figure 3.

Spectrum measured at the output of the compression stage of the speech processor for a marker laying on the headpiece either switched-off (top) or activated (bottom) in orientation xy. The level at the frequency of the input signal was normalized to 0 dB (sinusoid of 1 kHz, 65 dB SPL at microphone). Arrows show frequencies of potential 2nd and 3rd order distortion products resulting from interaction of the marker's magnetic field and the acoustic input signal. No distortion products were observed.

Table 1

Measured total-harmonic distortion plus noise (THD+N) at the output of the compression stage of the CI-processor. A sinusoidal tone of either 1000 Hz or 1010 Hz at 65 dB SPL was used as input signal, either fed through the microphone or the AUX input of the implant. The marker, which emits the magnetic field, was laying on the CI-system's headpiece in one of the defined basis-orientations (Figure 1).

Marker		Total harmonic distortion plus noise [dB]			
State	Orientation	Microphone input		AUX input	
		1000 Hz	1010 Hz	1000 Hz	1010 Hz
off	xy	-4.4	-4.2	-4.4	-4.3
	xy	-4.3	-4.2	-4.3	-4.3
on	xz	-4.2	-4.2	-4.5	-4.2
	yz	-4.4	-4.4	-4.2	-4.4