Physiological Impact of Vibration and Noise in an Open-air Magnetic Resonance Imager: Analysis of a PPG Signal of an Examined Person

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Motivation of Our Work

MR imaging is accompanied with vibration due to rapidly changing Lorenz forces in gradient coils producing significant mechanical pulses during execution of a scan sequence.

Mechanical vibrations and acoustic noise have physiological and psychical impact on the examined person inside the MRI device depending on the intensity and time duration of exposure.

The negative influence of the generated vibration and noise on a human body and psychic can be monitored by measuring the blood pressure and the heart rate during MR scanning.

For non-invasive acquisition of vital information about the cardiovascular system of the examined person the photoplethysmography (PPG) optical sensor together with a portable blood pressure monitor were used in our experiments.

Basic Description of the Investigated MRI Device

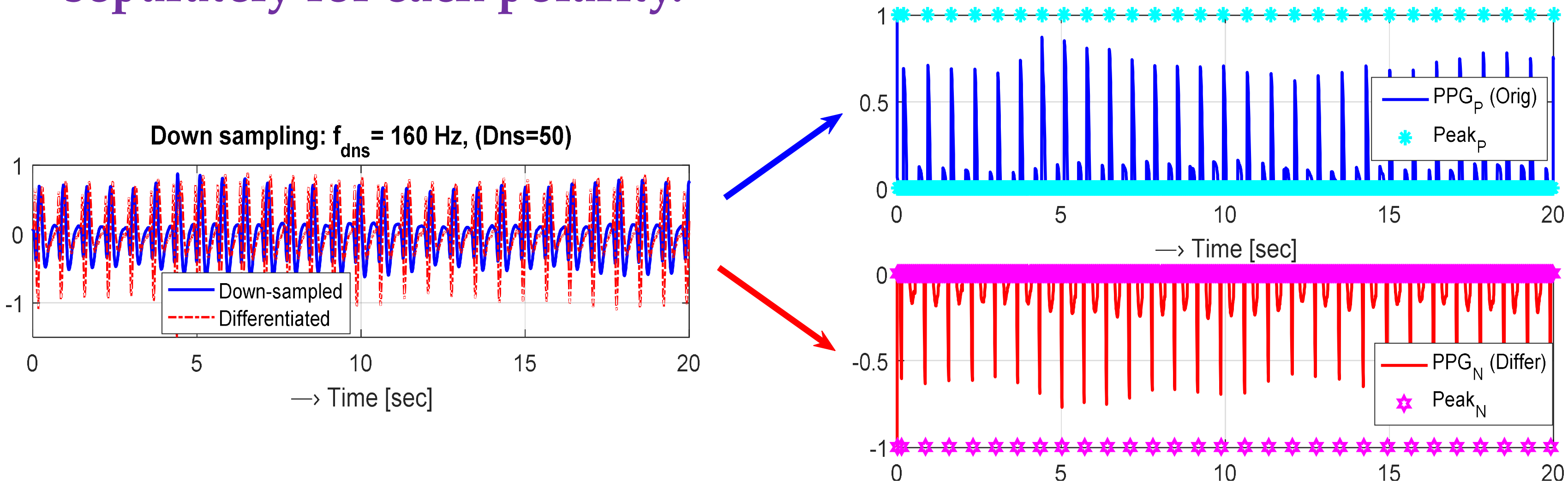
Open-air MRI equipment Esaote E-Scan Opera:

- a stationary magnetic field with $B_0 = 0.178$ T is produced by a pair of permanent magnets,
- the gradient system consists of 2 x 3 planar coils situated between the magnets and an RF receiving/transmitting coil with a tested object/subject.

Processing of the PPG Signal I.

The first phase of PPG signal processing:

- down-sampling of the original PPG signal *Dns*: $f_{dns} = f_s / Dns$,
- signal normalization, calculation of the first derivative,
- determination of the positive/negative polarity of the down-sampled/differentiated PPG signal,
- localization of maximum peak positions in the PPG signal separately for each polarity.

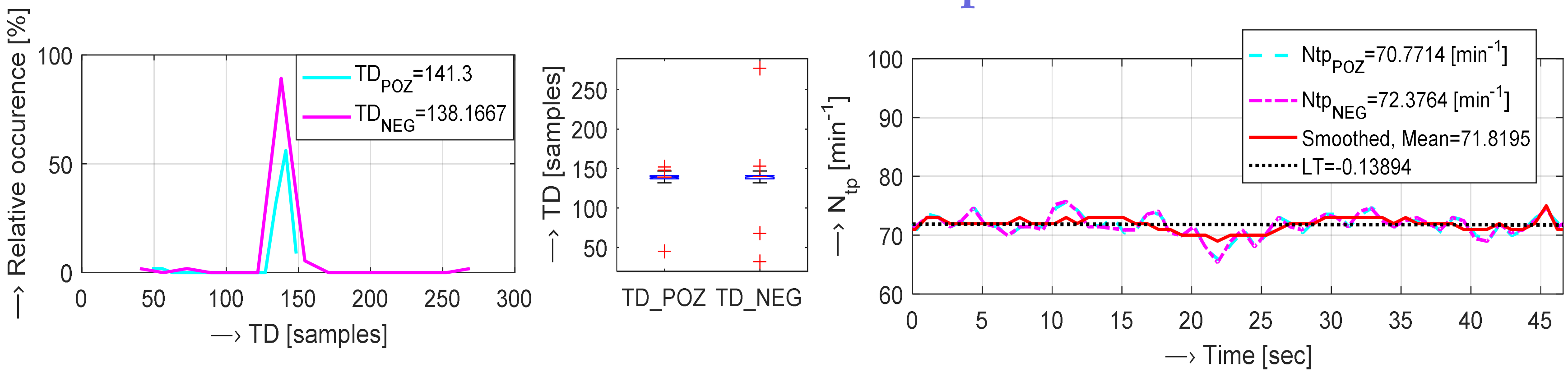


An example of the selected 20-s ROI from the recorded PPG signal together with its first derivative *(left)*, positive/negative peak positions of the down-sampled/differentiated PPG signal *(two graphs on the right)*; $f_s$orig = 8 kHz.

Processing of the PPG Signal II.

The second phase of PPG signal processing:

- **calculation of time distances (TD) between the localized peaks of both analyzed polarities of the PPG signal,**
- **building of histograms and box plots of basic statistical analysis of the obtained TD values; separately for each signal polarity,**
- **finding the maximum occurrence of TD values and calculation of the number of heart pulses for both polarities $N\text{tp}_{poz}$ and Ntp_{neg},**
- **smoothing output vectors of Ntp values joined for both polarities, determination of mean and linear trend parameters.**



An example of statistical processing: histograms of TD values for both signal polarities (left); box plot of basic statistical analysis of TD values (middle); Ntp curves for both polarities of the PPG signal, their smoothing, and the linear trend (right).

Description of the Performed Experiments

Two types of experiments were practically performed:

1) **Auxiliary measurement of three different types of portable blood pressure monitors – BPMs:**
   - **comparison of precision and stability of the HR values measured directly by the investigated BPM devices and determined from the PPG signals**

   ➡ **to choose the best BPM device for the measurement inside the MRI tomograph.**

2) **The main measuring experiment with the tested person lying in the MRI scanning area and simultaneous real-time recording of his/her PPG signal:**
   - **measurement for MR scan sequence running or for no scanner activity ("silent" case)**
   - **the BP and HR parameters of the tested person were measured also manually by a portable BPM.**

Comparison of the BPM Accuracy

Three BPM devices were tested and compared:

1) **Automatic blood pressure monitor with stroke risk detection BP A150-30 AFIB and a comfortable cuff produced by Microlife ,**
2) **Omron M6 upper arm BPM with Intelligent Wrap Cuff Technology by Omron,**
3) **Omron HEM-711 DLX with Comfit Cuff by Omron.**

Photo of the tested BPM device Microlife *(left)*, and of the BPM Omron M6 *(on the right)*.

Experimental Conditions for BPM Comparison

To obtain maximum range of the heart rate *N*tp , the PPG signal was recorded in different physiological situations:

→ **after book/journal reading, music listening, relaxation, drinking tea or coffee, physical activity, etc.**

The PPG signal was picked up from the pinkie of the right hand and the cuff was put on the left arm

➡ **to prevent any influence of an inflated pressure cuff of the BPM on a tested person's blood system.**

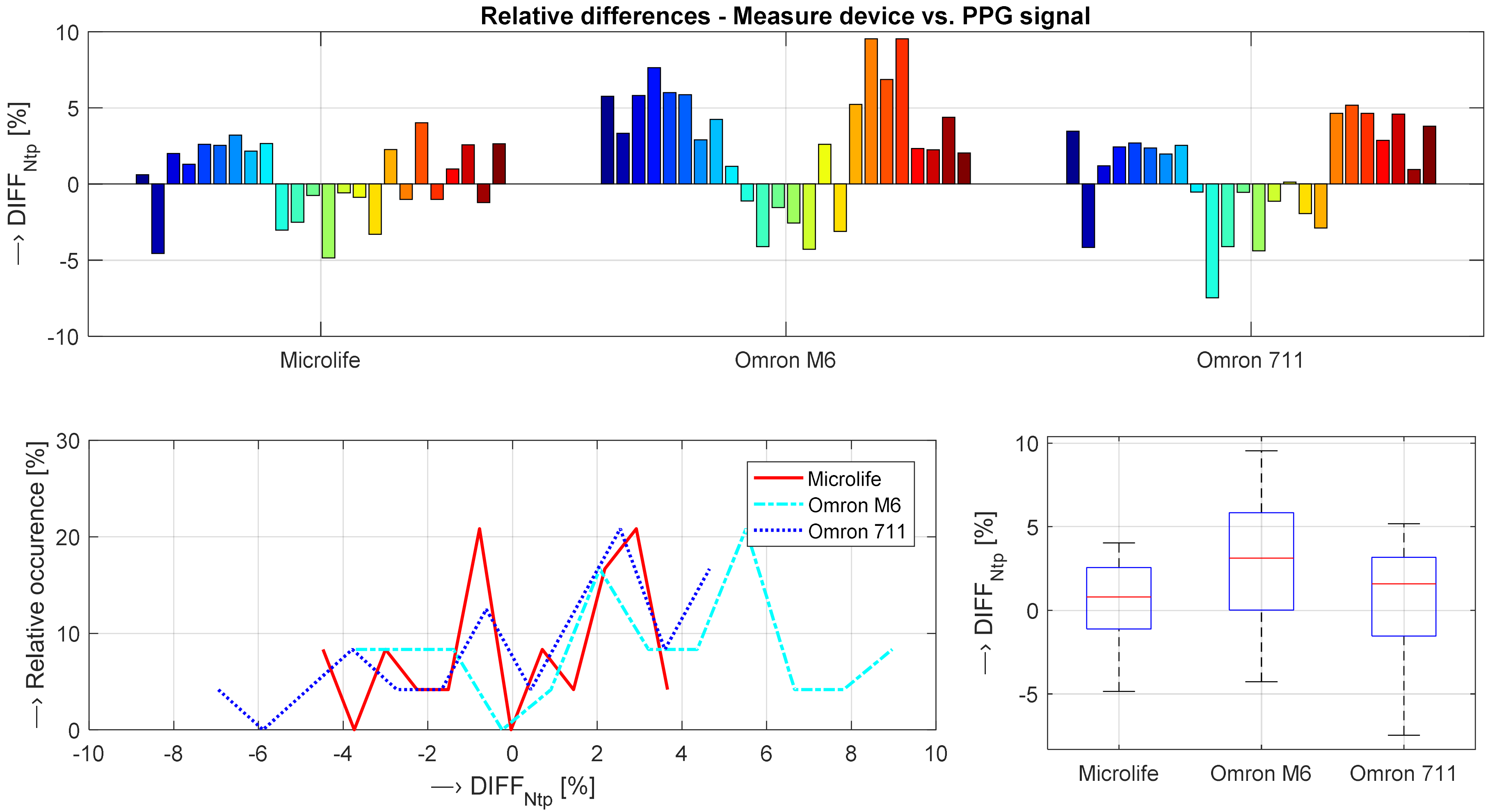
In this part of measurement :

→ **six volunteer persons (four males and two females in the age from 37 to 85) took part ,**

→ **12 data records per person were collected (72 in total).**

For final comparison, relative differences in [%] between Ntp values determined from the PPG signal and those measured by three tested BPMs were used.

Results of Comparison of the BPM Devices



Comparison of relative differences in [%] between N_{tp} determined from the PPG signal and three investigated BPM devices.

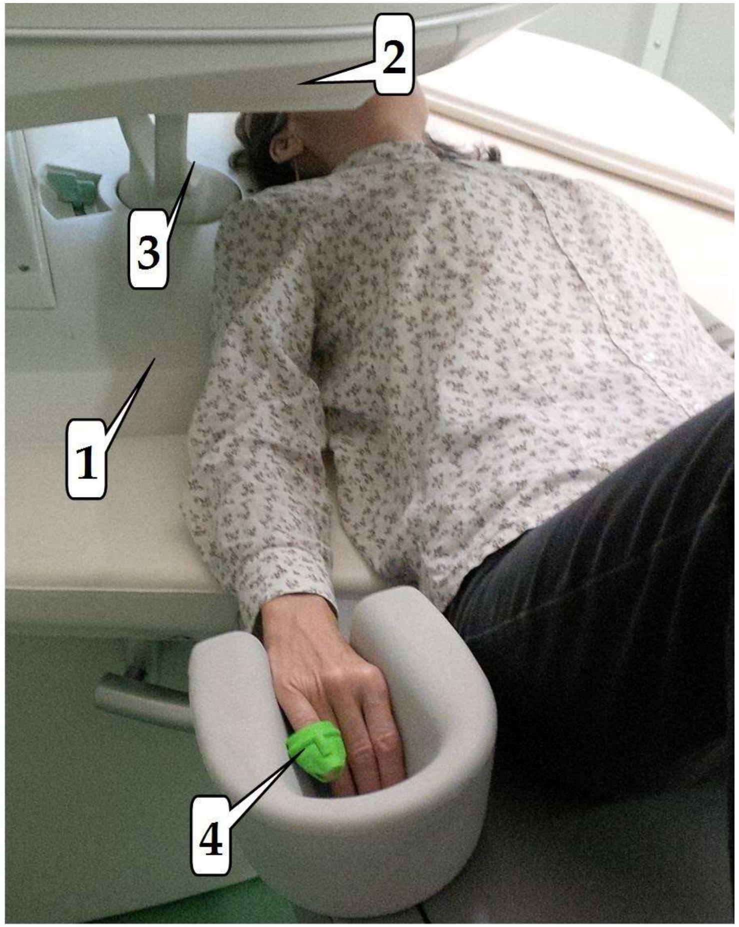
Proposal of Experiment for Analysis of MRI Vibration and Noise Effects by the PPG Signal

Phase	Description	Status	Measurement	T_{DUR} [2] [s]
F0s	Initialization and adaptation	Silent [1]	PPG signal recording	60
F1t	1st BP and HR measurement	Silent [1]	by BPM & PPG recording	60
F2m	1st vibration/noise exposition	MRI scanning	PPG signal recording	300
F3t	2nd BP and HR measurement	MRI scanning	by BPM & PPG recording	60
F4m	2nd vibration/noise exposition	MRI scanning	PPG signal recording	300
F5t	3rd BP and HR measurement	MRI scanning	by BPM & PPG recording	60
F6s	Relax after expositions	Silent [1]	PPG signal recording	300
F7t	4st BP and HR measurement	Silent [1]	by BPM & PPG recording	60

[1] Only temperature stabilizer noise is generated. [2] Total time duration is ***1200 s*** (20 min).

Arrangement of the Measuring Experiment

Overview of a testing person lying in the scanning area of the MRI Opera - a cuff of the BPM device on the left arm.



A detail of the scanning area: (1)/(2) – the lower/upper permanent magnet and the gradient coil, (3) – the middle point with the RF coil, (4) optical sensor for the PPG signal pick-up on the little finger of the right hand.

Conditions of the PPG Signal Recording

In real-time parallel recording of the PPG signal in the scanning area of the MRI device the following was used:

- **reflective optical sensor HRM-2511E *(by Kyoto Electronic Co.)* consisting of an infrared LED light source and a photo detector - worn on a little or a middle finger,**
- **analog interface Easy Pulse *(by Embedded Lab)* for further pre-amplification and two-phase filtering of the PPG signal,**
- **battery-based power supply of 5 V power bank AlzaPower Source 20000 via USB connection – to avoid 50 Hz disturbance and its harmonics from the power-line voltage,**
- **mixer device Behringer XENYX Q802 and digitization via the USB interface connected to the laptop PC,**
- **sampling frequency of 2 or 8 kHz, down-sampled to 160 Hz and further processed by the sound editor program Sound Forge 9.0a.**

The Main Measuring Experiment in the MRI Device

1. Two persons participated in this main measurement:

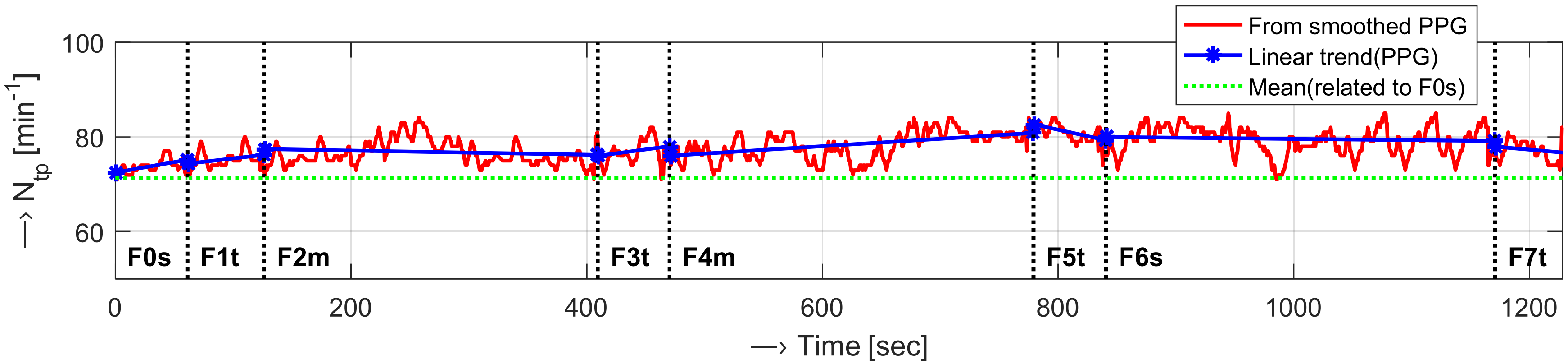
   → one male and one female weighing approximately 80/55 kg *(the weight affects spectral properties of the generated vibration and noise)*.

2. Position of the tested person was chosen is such a way that the head was placed in the RF scan coil between the upper and lower gradient coils of the MRI device to maximize the noise and vibration effect on an examined person.

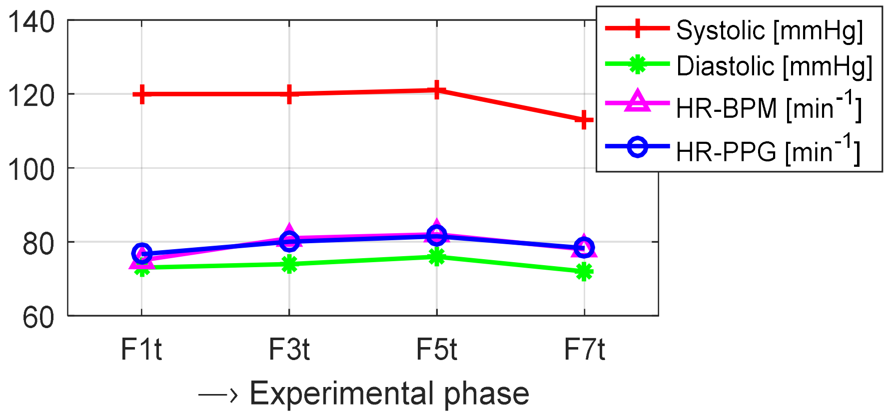
   → the 3D SSF sequence (TE=10 ms, TR=40 ms, 3D-phases=24, N_{ACC}=4, sagittal orientation, T_{DUR}=12:24 min) was used in the active stimulation phases (F2m and F4m) .

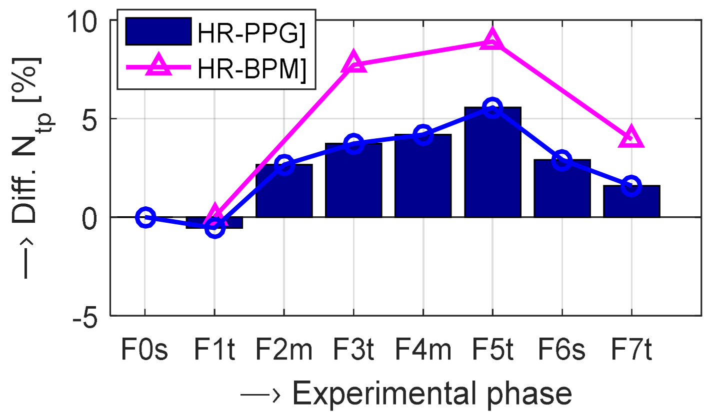
3. Only the optical sensor HRM-2511E was placed in the MRI scanning area; the electronic Easy Pulse sensor module with battery power supply and the audio mixer were located outside the shielding cage.

Results of PPG Signal Analysis in all 8 Phases



Visualization of the resulting PPG signals in 8 phases of the measuring experiment: filtered/smoothed, linear trend and mean relative to F0s phase for a tested male person.





Comparison of *N*tp/HR values from the PPG signal and by the BPM device: BPs and HR in four measuring phases (left graph); differences in all eight experimental phases relative to the phase F0s/F1t as a baseline (right graph).

Final Comparison of HR and BP Values

Final numerical comparison of HR and BP values in all eight phases
mean relative differences in [%] (and std values in braces)

Phase	From PPG signal [1]	BP and HR by BPM device [2]		
	Ntp	BP_{SYST}	BP_{DIAST}	*HR*
F0s	0 (0)	-	-	-
F1t	1.18 (0.46)	0 (0)	0 (0)	0 (0)
F2m	1.75 (0.54)	-	-	-
F3t	2.65 (0.67)	1.93 (0.88)	-1.44 (0.52)	6.06 (0.70)
F4m	2.77 (0.82)	-	-	-
F5t	**4.14** (1.06)	**2.67** (0.78)	**-1.95** (0.59)	**7.94** (0.74)
F6s	3.04 (0.86)	-	-	-
F7t	2.39 (0.61)	1.33 (0.89)	-0.09 (0.70)	5.77 (0.67)

[1] Relative to values of F0s phase as a baseline, [2] relative to values of F1t phase as a baseline.

Discussion and Conclusion

1. **The preliminary experiment shows that all three tested BPM devices give the heart rate values comparable with those determined from the PPG signal:**
   - ✓ **the BPM Microlife was finally used in the main experiment part to obtain the best statistical results**
     - → **minimal dispersion and approximately zero mean value of the calculated relative differences.**
2. **The main measurement experiment confirms that exposition to MRI vibration and noise affects the human physiology and psyche which is documented by**
   - ✓ **the mean increase of the *N*tp/HR values by 4/8 % in comparison with the silent state (initial phase F0s/F1t).**
3. **More statistically significant results can be obtained by carrying out more measuring experiments with different persons lying in the scanning area of the MRI device.**

Future plans:

– verification of the working hypothesis that the stress induced by vibration and acoustic noise of the MRI tomograph is manifested also in the voice of an examined person,

– parallel recording of a speech signal when a speaker lies in the scanning area of our tomograph as this arrangement is used in MR imaging of vocal folds during phonation.

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