Acquisition and Analysis of Human Carotid Pulse Waveforms during Tilt Table Maneuvers

Sharda Vashisth 1, Munna Khan 2, Ritu Vijay 3, and Ashok K. Salhan 4,

ABSTRACT

The push-pull effect has a great role in acceleration protection research especially for G-LOC (G-induced loss of consciousness). Cardiac rate is considered vital mechanism of response to push pull effect. Various methods based on different physical principles have been developed to measure the cardiac rate to identify the effects of postural changes during the tilt table test. Carotid signal acquired from the subject with the help of piezoelectric sensor may be used to evaluate the cardiovascular activity of the subject. The subject is positioned onto the tilt table facing upward with his back against the tilt table. A noninvasive system has been developed in which a piezoelectric sensor is placed on the carotid artery of the subject. Carotid signals of ten human subjects are acquired during a complete Head Up-Head Down-Head Up movement in pitch rotation of the tilt table. The Carotid signal is acquired and filtered using MATLAB software. RR intervals and pulse amplitudes are computed from the carotid signal recordings. The technique used in the developed system can be applied to measure and counter the G stress occurring on aircraft pilots during push pull maneuvers.

Keywords: Carotid pulse, Push pull effect, Piezoelectric sensor, Tilt table, Biological Engineering

1. INTRODUCTION

Push pull effect (PPE) is one such entity, which has generated great interest and concern among the aviation medicine community since the last decade. The phenomenon of G transition in reducing the +Gz tolerance preceded by less than +1Gz (relative Gz) is termed as Push-Pull effect [1-3]. The push-pull effect has a great role in acceleration protection research especially for G-LOC. Many methods have been used to study and analyze G stress and push pull effect. The push-pull maneuver (PPM) is defined as a drop in G-tolerance when positive acceleration (+Gz) immediately follows negative acceleration (-Gz), with the carotid baroreceptors apparently playing a dominant role in the resulting BP [10] responses. In [4] it is clearly shown that multilayer perceptron neural network employing quick propagation training algorithm is efficient to identify internal carotid artery stenosis and occlusion. In [5] a noncontact photoelectric plethysmograph is designed to determine intraocular blood volume pulsations. A noninvasive study of alterations of the carotid arterial segments is done using images obtained through ultrasound scanning in B-mode [6] and the measured diameter is plotted as a graph and pulsatile changes of the artery are determined to study the effect of age on carotid artery. In [7] the centrifuge of the Military Institute of Aviation Medicine was modified to allow active positioning of the gondola during rotation get Head-down position of -6 degrees to -40 degrees to produce relative -Gz (r-Gz) in a range down to 0.2. The trainees experienced the push-pull effect, which enforced them to begin an anti-G straining maneuver at lower levels than normal. The push-pull maneuver [8] is simulated on a single-axis human centrifuge using (lower body positive pressure (LBPP). The physiologic effects of LBPP are observed similar to those of Gz and decreased tolerance to +Gz is noticed. In contrast to this lower body negative pressure (LBNP) rotating-table [9] was used to explore the effect of push-pull effect (PPE) and the physiological responses to push-pull maneuver were observed. After headstand, head-up stand combining LBNP caused cardiovascular function go down, the degree was bigger than simple head-up stand combining LBNP. In [10] it is observed that application of neck pressure (NP) during the preceding -Gz phase maintains +Gz tolerance during following +Gz. In [11] arterial pressure changes were investigated under orostatic stress by exposing subjects to head up to head down and to head up again in either pitch or roll rotations. The results of [12] agree with the statistical study results obtained in [11]. In [13] subjects were tested during non accelerated horizontal flight for two states, one during radial acceleration and other during the weightless condition and it is concluded that acceleration thresholds of reversible and irreversible injury is lower in space flight conditions than in the one G field of man’s earthly environment. Push pull effect Maneuvers (PPEMs) were detected [14] in 11 to 67% of the cases assessed. Observed PPEMs had segments of less than +1 Gz which varied from 0.0 to 0.5 Gz for an average of 3.5 to 5 s duration.

It is observed through various research works that
different artery pulses play important part in detecting cardiovascular functions for different postures. In [15] results showed that pulse transit time (PTT) is more responsive method for determining cardiac functions in response to leg crossing postures than Heart Rate Variability (HRV). Signal length of measured (Electrocardiogram) ECG is an important parameter to determine HRV. HRV determined based on three minutes measured ECG signal is not found equal to that of five minutes measured signal [16]. A patient compliant ECG beat classification system based on a similarity function and a beat database is presented in [17]. A piezoelectric sensor based system is suggested in [18-22] to acquire carotid signal. A prototype system is developed which includes analog system and a FM transceiver pair interfaced through sound port of the computer to obtain real time cardiac data.

In the present work the developed system comprises of piezoelectric sensor, personal computer, MATLAB software [23] and the experiments are conducted on the tilt table. Carotid signals of the subjects are recorded during head up tilt (70 degrees) and reversal of the tilt. During each test, the subject is placed onto the tilt table with his/her feet held to the foot support plate. The subject faces upward with his back against the tilt table. Carotid signals are measured during a complete Head Up-Head Down-Head Up movement in pitch rotation.

A piezoelectric sensor having metallic plate of 2.0 cm diameter and 0.25 mm thickness is used. Ceramic layer of diameter 1.30 cm with a thickness of 0.1 mm is coated over this metallic plate. The sensor is interfaced to the sound port of the computer where it is amplified and converted to digital signal. Data acquisition and signal processing toolboxes of MATLAB software are used to read signal from the sound port of the computer and filter it subsequently.

2. MATERIALS AND METHODS

The experimental set up for real time acquisition of carotid pulse waveform of the subject on the tilt table during a complete Head Up-Head Down-Head Up movement in pitch rotation is shown in Fig. 1. Practical block diagram of the complete system for acquisition of the carotid pulse from the subject on the tilt table is shown in Fig. 2. The complete developed system comprises of piezoelectric sensor, personal computer, MATLAB software and the experiments are conducted on the tilt table.

Ten healthy subjects participated in this work. All of the subjects had experience with the tilt table earlier. Experiments are conducted using the head up tilt table which is developed by Dr KK Deepak at All India Institute of Medical Sciences (AIIMS). The tilt table can be used for the postural changes test. The carotid signals of the subjects are recorded during head up tilt (70 degrees) and reversal of the tilt. During each test, the subject is placed onto the tilt table with his/her feet held to the foot support plate. The subject faces upward with his back against the tilt table. Carotid signals are measured during a complete Head Up-Head Down-Head Up movement in pitch rotation.

A piezoelectric sensor having metallic plate of 2.0 cm diameter and 0.25 mm thickness is used. Ceramic layer of diameter 1.30 cm with a thickness of 0.1 mm is coated over this metallic plate. The sensor is interfaced to the sound port of the computer where it is amplified and converted to digital signal. Data acquisition and signal processing toolboxes of MATLAB software are used to read signal from the sound port of the computer and filter it subsequently.

The subject is positioned onto the tilt table with his/her feet held to the foot support plate. The subject is asked to face upward with his back against the
Filtered Carotid Pulse & Digital Filtering

MATLAB Software

Personal Computer

Human Subject on the tilt table

Carotid Pulse of the subject

Piezoelectric Sensor

Sound Card

**Fig.2:** Practical block diagram of the complete system for acquisition of the carotid pulse signal of the subject positioned on the tilt table

**Fig.3:** Raw Carotid signal and filtered carotid signal of subject 3 when the tilt table is at 0 degree (Bessel) position

tilt table. After properly examining the palpitation of the carotid artery on the neck, piezoelectric sensor is placed on the artery. The sensor is interfaced to the sound port of the computer with the help of mono jack and carotid signal is recorded. Subjects’ bessel signal for 30s was recorded first. Then the subject was moved to head up 70 degrees, it took him to go up in 19 seconds and was kept in that position for another 11s. So in total for 30s the signal was recorded. Again he was brought to 0 degrees and carotid pulse was recorded for another 30s. Then the subject was moved to head down 70 degrees and again it took him 19s to go HD and was kept in that position for another 11s. So in total for 30s signal was recorded. Then he was brought to 0 degrees again and the signal was recorded for 30s again. Carotid signals are recorded during a complete Head Up-Head Down-Head Up movement in pitch rotation.

This noninvasive method is used on 10 healthy male and female subjects of age groups between 30-51 years in head up tilt (70 degrees) and reversal of the tilt positions. The acquired raw signal is then filtered using FIR digital filters in MATLAB. For real time acquisition and offline digital filtering of the carotid pulse, MATLAB (matrix laboratory) which is a numerical computing environment is used. In the present work for acquisition of the signal sound port is used. MATLAB identifies the sound port as "winsound". Single channel is added to the sound port using "get (ai, 'channel')" command. Analog input object "ai" is created using "analoginput ('winsound')" command. Sample rate and samples per trigger are chosen to fix the duration for which signal is acquired. After setting the analog input object, "ai" is started with command "start (ai)" and after collecting the signal it is plotted using command "plot".

As analog input object is no longer required "delete" command is used to free the memory. The online carotid pulse is thus acquired and stored. Digital FIR filter and zero phase band pass filtering are used to reduce the noise and interfering signals in the real time acquired carotid signal. Band pass filter with pass band 0.05-5 Hz is used as the digital filter which covers normal to normally excited heart beat intervals. The 'filtfilt' command is used for Zero-phase forward and reverse digital filtering. The command filtfilt(b, a, x) filters the data in vector X with the filter described by vectors a and b to create the filtered data y. The filtered sequence is reversed and run back through the filter after filtering in the forward...
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3. RESULTS

Carotid pulse waveforms of human subjects positioned on the tilt table are recorded during a complete Head Up-Head Down-Head Up movement in pitch rotation. The carotid pulse waveforms are obtained for all 10 subjects in different positions of the tilt table. First of all bessel signal of the subject for 30 seconds is recorded when the tilt table is at 0 degree. Raw Carotid signal and filtered carotid signal of subject 3 when the tilt table is at 0 degree (Bessel) position is shown in Fig. 3. Then the tilt table was moved to head up 70 degrees position, it took him to go up in 19 seconds and was kept in this position for another 11 seconds. So in total for another 30 seconds the signal is recorded. Filtered carotid signal of subject 3 when the tilt table is at 70 degrees Head up (HU) position is shown in Fig. 4. The subject is again brought to 0 degree and carotid pulse is recorded for another 30 seconds. Raw Carotid signal and filtered carotid signal of subject 3 when the tilt table is at 0 degree (After HU) position is shown in Fig. 5. Bessel signal of the signal is recorded again before moving the tilt table to HD position. Filtered signal of subject 3 is shown in Fig. 6 when the tilt table is at 0 degree before Head down (Bessel) position. Then the subject is moved to head down 70 degrees and again it took him 19 seconds to go HD position and is kept in that position for another 11 seconds. So in total for another 30 seconds the signal is recorded. Filtered carotid signal of subject 3 is shown in Fig. 7 when the tilt table is at 70 degrees head down (HD)
Fig. 6: Filtered signal when the tilt table is at 0 degree before Head down (Bessel) position

Fig. 7: Filtered carotid signal of subject 3 when the tilt table is at 70 degrees Head down (HD) position

Fig. 8: Filtered carotid signal of subject 3 when the tilt table is at 0 degree after Head down (HD) position

position. Subject then is brought to 0 degrees again and the signal is recorded for 30 seconds again. Filtered carotid signal of subject 3 is shown in Fig. 8 when the tilt table is at 0 degree after head down (HD) position. Carotid signals of all the subjects are recorded and compared during a complete Head Up-Head Down-Head Up movement in pitch rotation.

These recordings of the subjects at different positions are analysed for changes in pulse amplitude and RR interval. The developed system in the present work may not be giving a standard carotid signal but it can be competently used for finding RR interval and pulse amplitude. Table 1 and Table 2 shows RR interval and pulse amplitude of all subjects in different positions of the tilt table respectively. RR interval and pulse amplitude are determined by visual inspection. RR interval in head up 70 degrees position is reduced which indicates higher heart rate. Decrease in pulse amplitude is noticed in case of head up position and increase in pulse amplitude is noticed in case of head down position. In contrast to head up position, increase in RR interval is observed in case of head down 70 degrees position which indicates slower heart rate. Increase in pulse amplitude is noticed in case of head down position.

4. DISCUSSION

Present work shows that the carotid pulse is an important physiological parameter which can be used to
Table 1: shows RR interval of all subjects during different tilt table positions.

<table>
<thead>
<tr>
<th>Position</th>
<th>0 degree (Bessel)</th>
<th>70 degrees (HU)</th>
<th>0 degree (After HU)</th>
<th>0 degree (Bessel before HD)</th>
<th>70 degrees (HD)</th>
<th>0 degree (After HD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>RR interval (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.75</td>
<td>0.62</td>
<td>0.75</td>
<td>0.81</td>
<td>0.87</td>
<td>0.62</td>
</tr>
<tr>
<td>2</td>
<td>1.05</td>
<td>0.75</td>
<td>0.87</td>
<td>0.92</td>
<td>1.15</td>
<td>0.75</td>
</tr>
<tr>
<td>3</td>
<td>0.75</td>
<td>0.68</td>
<td>0.75</td>
<td>0.83</td>
<td>0.87</td>
<td>0.72</td>
</tr>
<tr>
<td>4</td>
<td>0.83</td>
<td>0.75</td>
<td>0.82</td>
<td>0.87</td>
<td>0.92</td>
<td>0.77</td>
</tr>
<tr>
<td>5</td>
<td>0.68</td>
<td>0.63</td>
<td>0.70</td>
<td>0.75</td>
<td>0.77</td>
<td>0.60</td>
</tr>
<tr>
<td>6</td>
<td>1.15</td>
<td>0.85</td>
<td>0.90</td>
<td>0.96</td>
<td>1.20</td>
<td>0.90</td>
</tr>
<tr>
<td>7</td>
<td>0.90</td>
<td>0.77</td>
<td>0.85</td>
<td>0.95</td>
<td>1.05</td>
<td>0.85</td>
</tr>
<tr>
<td>8</td>
<td>0.84</td>
<td>0.65</td>
<td>0.79</td>
<td>0.85</td>
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<td>0.75</td>
</tr>
<tr>
<td>9</td>
<td>0.96</td>
<td>0.77</td>
<td>0.80</td>
<td>0.85</td>
<td>0.95</td>
<td>0.70</td>
</tr>
<tr>
<td>10</td>
<td>0.90</td>
<td>0.71</td>
<td>0.75</td>
<td>0.80</td>
<td>0.88</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Table 2: shows pulse amplitude of all subjects during different tilt table positions.

<table>
<thead>
<tr>
<th>Position</th>
<th>0 degree (Bessel)</th>
<th>70 degrees (HU)</th>
<th>0 degree (After HU)</th>
<th>0 degree (Bessel before HD)</th>
<th>70 degrees (HD)</th>
<th>0 degree (After HD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>RR interval (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.0</td>
<td>0.25</td>
<td>0.5</td>
<td>0.5</td>
<td>1.3</td>
<td>0.6</td>
</tr>
<tr>
<td>2</td>
<td>1.7</td>
<td>0.7</td>
<td>0.91</td>
<td>1.0</td>
<td>2.2</td>
<td>1.3</td>
</tr>
<tr>
<td>3</td>
<td>0.9</td>
<td>0.25</td>
<td>0.25</td>
<td>0.7</td>
<td>1.5</td>
<td>0.5</td>
</tr>
<tr>
<td>4</td>
<td>0.75</td>
<td>0.2</td>
<td>0.2</td>
<td>0.65</td>
<td>1.2</td>
<td>0.5</td>
</tr>
<tr>
<td>5</td>
<td>0.85</td>
<td>0.5</td>
<td>0.5</td>
<td>0.7</td>
<td>1.0</td>
<td>0.45</td>
</tr>
<tr>
<td>6</td>
<td>0.77</td>
<td>0.25</td>
<td>0.25</td>
<td>0.6</td>
<td>0.95</td>
<td>0.25</td>
</tr>
<tr>
<td>7</td>
<td>0.9</td>
<td>0.3</td>
<td>0.35</td>
<td>0.7</td>
<td>1.3</td>
<td>0.50</td>
</tr>
<tr>
<td>8</td>
<td>1.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.85</td>
<td>2.0</td>
<td>0.85</td>
</tr>
<tr>
<td>9</td>
<td>1.4</td>
<td>0.45</td>
<td>0.5</td>
<td>0.9</td>
<td>1.8</td>
<td>0.75</td>
</tr>
<tr>
<td>10</td>
<td>0.9</td>
<td>0.3</td>
<td>0.4</td>
<td>0.75</td>
<td>1.1</td>
<td>0.7</td>
</tr>
</tbody>
</table>

deduce cardiac information. Researchers nowadays are paying more attention on noninvasive determination of pulse pressure waveform from peripheral artery [19, 24-25]. The most commonly used principle to record the pressure waveform is applanation tonometry using a strain gauge sensor placed over a pulsating artery [25-26]. To determine the pressure pulse waveform volume clamp principle of Jen Penaz and an infrared photoplethysmographic finger cuff is also used [27-28]. Another techniques used are carotid artery ultrasound and pulse wave analysis enable noninvasive quantification of ventriculoarterial responses to changes in posture as mentioned in [29]. A photo electric plethysmograph is used to determine intraocular blood volume pulsations for evaluation of carotid stenosis [5]. In [10] a simple cost effective system is designed to measure carotid pulse which includes a band, an artery pressing air cell, an inflating/delating device and a pressure detection unit.

In [7-15] effect of G stress during posture changes are determined using different platforms. Gondola, tilt table, centrifuge are the platforms used in [7-15] where the decreased tolerance to G stress is noticed. Similarly, in this work single sensor based system is developed which is capable of acquiring satisfactory carotid pulse signal in real time which further can be used to quantify and administer push pull and G stress effect on aircraft pilot. The tilt table is used for the postural changes test. The carotid signals of the subjects are recorded during head up tilt (70 degrees) and reversal of the tilt. During each test, the subject is placed onto the tilt table with his/her feet held to the foot support plate. The subject faces upward with his back against the tilt table. Carotid signals are measured during a complete Head Up-Head Down-Head Up movement in pitch rotation. The anticipated method does not involve any intricate electronic circuitry which makes it quite effective for investigating carotid pulse signal. The carotid pulse signal is then processed and analysed using application softwares. The developed system is cost efficient and is proficient of retrieving the cardiac information from the attained physiological signal during different tilt table positions.

5. CONCLUSION

Cardiac rate is considered vital mechanism of response to push pull effect. Carotid signal is significant physiological parameter which may be used to gather cardiac information. Single sensor based developed
system is competent of acquiring satisfactory carotid signal in real time during a complete Head Up-Head Down-Head Up movement in pitch rotation of tilt tables which further can be used to measure and manage G stress effect on aircraft pilot. The carotid pulse signal can then be processed and analysed using application softwares. The system is cost efficient and is dependable for retrieving the cardiac information from the acquired physiological signal. RR interval and pulse amplitude are determined by visual inspection. RR interval in head up 70 degrees position is reduced which indicates higher heart rate. Decrease in pulse amplitude is noticed in case of head up position. In contrast to head up position, increase in RR interval is observed in case of head down 70 degrees position which indicates slower heart rate. Increase in pulse amplitude is noticed in case of head down position.

This cost effective developed system is able to capture and analyse cardiac information in various body postures which might be further used for monitoring and analysing G stress and push pull effect on real time fighter plane pilots.

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These experiments were possible only by the thorough co-operation of doctors and staff at AIIMS, Delhi, India. The author is especially indebted to Dr. K. K. Deepak, Professor of Physiology at AIIMS for his unconditional support. Last, but not least, we want to recall the co-operation of the subjects, who volunteered for this task, which was for them not always very comfortable.

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Sharda Vashisth is working as Assistant Professor in Electrical, Electronics & Communication Engineering Department at ITM University, Gurgaon. She is doing her Ph.D from Banasthali University, Banasthali and her field of specialization is biomedical electronics and digital signal processing. She has papers in national and international conferences and journals to her credit.

Munna Khan is Professor in Electrical Engineering Department at Jamia Milia Islamia University, New Delhi. Dr. Khan is a gold medallist from IIT Delhi and has his doctorate in the field of biomedical instrumentation. He has many papers in national and international journals and conferences. Dr. Khan is guiding many research scholars.

Ritu Vijay is Associate Professor and Head of the Electronics Department, Banasthali University, Banasthali. Dr. Ritu Vijay has acquired her doctorate in electronics engineering and her field of specialization is digital signal processing and embedded system design. She has many papers in national and international journals and conferences. Dr. Ritu Vijay is guiding many research scholars.

Ashok K. Salhan is Additional Director at Defence Institute of Physiology and Allied Sciences, DRDO. Dr. Salhan has the degree of MBBS and has a vast knowledge and experience in the field of bio-medical instrumentation and analysis. He has many papers in national and international journals to his credit.