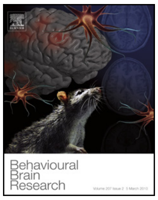
Behavioural Brain Research 278 (2015) 330–336

Contents lists available at ScienceDirect

Behavioural Brain Research

journal homepage: www.elsevier.com/locate/bbr



Research report

Cerebral autoregulation in response to posture change in elderly subjects-assessment by wavelet phase coherence analysis of cerebral tissue oxyhemoglobin concentrations and arterial blood pressure signals

Yuanjin Gao[a], Ming Zhang[b], Qingyu Han[a], Wenhao Li[a], Qing Xin[c], Yan Wang[b], Zengyong Li[a,*]

[a] *Key Laboratory of High Efficiency and Clean Mechanical Manufacture, School of Mechanical Engineering, Shandong University, Jinan 250061, PR China*
[b] *Interdisciplinary Division of Biomedical Engineering, Faculty of Engineering, The Hong Kong Polytechnic University, Kowloon, Hong Kong, SAR, PR China*
[c] *Hospital of Shandong University, Jinan 250061, PR China*

HIGHLIGHTS

- Phase coherence between cerebral Delta [HbO_2] and blood pressure was analyzed.
- Sit-to-stand change induces low wavelet phase coherence in elderly subjects.
- Stand-to-sit change induces high wavelet phase coherence (WPCO) in elderly subjects.
- Difference in WPCO indicates an altered cerebral autoregulation due to aging.

ARTICLE INFO

Article history:
Received 23 August 2014
Received in revised form 7 October 2014
Accepted 12 October 2014
Available online 18 October 2014

Keywords:
Cerebral tissue oxygenation
Spontaneous oscillations
Near-infrared spectroscopy
Wavelet phase coherence
Aging

ABSTRACT

This study aims to assess the dynamic cerebral autoregulation (dCA) in response to posture change using wavelet phase coherence (WPCO) of cerebral tissue oxyhemoglobin concentrations (Delta [HbO_2]) and arterial blood pressure (ABP) signals in healthy elderly subjects. Continuous recordings of near-infrared spectroscopy (NIRS) and ABP signals were obtained from simultaneous measurements in 16 healthy elderly subjects (age: 68.9 ± 7.1 years) and 19 young subjects (age: 24.9 ± 3.2 years). The phase coherence between Delta [HbO_2] and ABP oscillations in six frequency intervals (I, 0.6–2 Hz; II, 0.15–0.6 Hz; III, 0.05–0.15 Hz; IV, 0.02–0.05 Hz, V, 0.0095–0.02 Hz and VI, 0.005–0.0095 Hz) was analyzed using WPCO. The sit-to-stand posture change induces significantly lower WPCO in interval III ($F = 5.50$ $p = 0.025$) in the elderly subjects than in the young subjects. However, the stand-to-sit posture change induces higher WPCO in intervals II ($F = 5.25$ $p = 0.028$) and V ($F = 6.22$ $p = 0.018$) in the elderly subjects than in the young subjects. The difference of WPCO in response to posture change between the elderly and the young subjects indicates an altered CA due to aging. This study provides new insight into the dynamics of CA and may be useful in identifying the risk for dCA processes.

1. Introduction

Dynamic studies of cerebral autoregulation (CA) quantify the rapid changes in cerebral blood flow velocity (CBFV) in a major cerebral artery in relation to the rapid alterations in arterial blood pressure (ABP) [1]. Posture change induces a transient change in mean ABP [2]. The brain vasculature must respond to changes in ABP or intracranial pressure to maintain stable cerebral blood flow (CBF) by the protective mechanism of the brain of CA [1]. Therefore, cerebral blood vessels have an inherent ability to keep the CBF fluctuation around certain value through myogenic, neurogenic, or metabolic mechanisms [1,3]. However, the CA can become impaired with ageing and thus resulting in orthostatic hypotension and related cerebral symptoms, such as lightheadedness, dizziness, falls or even syncope in elderly subjects [4].

It has been demonstrated that supine-to-standing posture change has significant effect on the frontal cortical HbO_2 in healthy elderly subjects. Mehagnoul-Schippe [5] found that elderly subjects

---

* Corresponding author. Tel.: +86 531 8839 5624; fax: +86 531 8839 2863.
E-mail address: zyongli@sdu.edu.cn (Z. Li).

http://dx.doi.org/10.1016/j.bbr.2014.10.019

Table 1
Frequency intervals and their possible physiological origins [17].

Interval	Frequency (Hz)	Physiological origin
I	0.6–2	Cardiac activity
II	0.15–0.6	Respiration
III	0.05–0.15	Myogenic activity
IV	0.02–0.05	Neurogenic activity
V	0.0095–0.02	Endothelial metabolic activity
VI	0.005–0.0095	Endothelial activity

experienced significant declines in frontal cortical oxyhemoglobin concentration [HbO_2] during supine-to-standing posture change, whereas these variables did not change significantly in the young subjects. Edlow [6] found that healthy aging alters the magnitude of change in frontal cortical HbO_2, but not cerebral blood flow (rCBF), total hemoglobin concentration (THC) or Hb during supine-to standing posture change.

A single sit-to-stand posture change is a straightforward technique to assess dynamic cerebral autoregulation (dCA), which is well tolerated in elderly subjects [1]. The sit-to-stand procedure is a useful and feasible method to test dCA in elderly subjects, which represents a physiologic challenge that occurs in daily life [1]. It was demonstrated to induce a depressor change in BP and CBFV [7]. Although the response of CA to posture change has been the subject of many studies, the interaction between the cerebral regulation and cardiovascular mechanisms is still far from comprehensive during sit-to-stand posture change.

Near-infrared spectroscopy (NIRS) is a promising technique for studying brain function during rest or task [8,9]. Spontaneous oscillations are generally found in the spectral analysis of changes in cerebral tissue oxyhemoglobin concentrations (Delta [HbO_2]) signals measured using near-infrared spectroscopy (NIRS) [10,11] as well as arterial blood pressure (ABP) signals [12,13]. Tachtsidis [14] found that posture change induced a significant increase in oscillatory changes in oxyhemoglobin concentration [HbO_2] and diastolic blood pressure (DBP). However, the power spectra of Delta [HbO_2] and ABP signals exhibit oscillations in various frequency bands. Wavelet analysis via the Morlet wavelet can detect these oscillations with logarithmic frequency resolution [11,15–18]. Different characteristic frequencies of cardiovascular signals, which indicate possible regulatory mechanisms, have been identified using wavelet analysis [17] (Table 1). The oscillations in intervals I and II reflect the effects of cardiac and respiratory activities, respectively [11,16,17]. Within the brain, interval IV is closely regulated through tight neurovascular coupling and partial autonomic control [3]. The cerebral oscillations in interval III (0.05–0.15 Hz) were suggested to originate locally from intrinsic myogenic activity of smooth muscle cells in resistance vessels and this myogenic mechanism may be partly under autonomic control [13,17]. The oscillations in frequency intervals V and VI were identified and investigated by Stefanovska [19] and Kvandal [20,21], which correspond to nitric oxide (NO)-related endothelial activity and NO-independent endothelial activity, respectively.

The wavelet phase coherence (WPCO) can reveal possible relationships by evaluating the match between the instantaneous phases of two signals [22,23]. WPCO analysis has been used to analyze the relationships between oscillations in skin blood flow, temperature and oxygen saturation within certain frequency ranges [18,22]. WPCO analyses here were used to test the hypothesis that changes in ABP are transmitted into changes in Delta [HbO_2] during posture change, and that this dynamic relationship is altered in elderly subjects because of aging. This study can provide new insight into the dynamics of CA and may be useful in identifying the risk for dCA processes.

Table 2
Characteristics of the participants.

Characteristic	Young	Elderly	*p* For difference
Age (years)	24.9 (3.2)	68.9 (7.1)	0.000**
Body mass index (BMI)	21.3 (2.5)	24.0 (2.9)	0.016*
Female sex	31.5%	37.5%	0.374
Systolic blood pressure (mm Hg)	116.9 (12.6)	122.4 (10.5)	0.460
Diastolic blood pressure(mm Hg)	68.7 (6.3)	72.8 (8.1)	0.520

Values are presented as means and standard deviations and percentages. *p* Values for differences are calculated using *t*-test for means and standard deviations, and Chi-square test for percentages, * <0.05, ** <0.01.

2. Methods

2.1. Subjects

A total of 35 healthy subjects were studied: 16 elderly (age: 68.9 ± 7.1 years) and 19 young (age: 24.9 ± 3.2 years). Table 2 shows the characteristics of the participants. Excluded from the study were subjects with hypertension; diabetes mellitus; subarachnoid hemorrhage; insufficiency of the heart, lungs, kidneys and liver; smoking or drinking habits, and additional medications (angiotensin-converting enzyme, inhibitors/angiotensin II-receptor blockers, and calcium-channel blockers). A diagnosis of hypertension was made when systolic blood pressure (SBP) ≥ 140 mm Hg or diastolic blood pressure (DBP) ≥ 90 mm Hg [24]. A diagnosis of diabetes mellitus was based on clinical assessment or fasting serum glucose level. The study was approved by the Human Ethics Committee of Shandong University and was in accordance with the ethical standards specified by the Helsinki Declaration of 1975 (revised in 1983).

2.2. Experimental procedures

Prior to the experiment, basic subject information, including age, weight, height, and ABP was recorded. Informed consent was obtained from all subjects. No alcohol and caffeine drinks were permitted 12 h prior to experimental testing. Subjects were instructed to be familiarized with the study protocol.

After instrumentation and when a stable ABP signal was obtained, the subjects assumed a sitting position for 15 min, after which they stood up within 10 s and remained standing for 15 min and a further 15 min of sitting rest. When changing position from sitting to standing, the ABP probe remains in the same spatial in relation to the heart, and thus avoiding the issue of a possible hydrostatic effect on cerebral perfusion pressure [1]. The subject was instructed to sit down if a subject developed syncope or pre-syncopal symptoms.

2.3. Measurement

Data for the NIRS and ABP signals were obtained from simultaneous measurements. After the age, height and body mass of the participants were recorded, NIRS measurements were performed on the subjects in a comfortable sitting posture using the tissue saturation An Heng monitor (TAH-100, developed by Tsinghua University, China). This equipment has been previously described in detail by Li [11,15,16]. In brief, the TSAH-100 sensor consisted of a two-wavelength LED and two PIN diodes. The LED component served as the source of emitted light at 760 and 850 nm, whereas the PIN diodes served as the detectors. Photons can penetrate the overlying tissues into the cerebral cortex (gray matter) when the distance between the detector and the source is ≥30 mm. Moreover, the penetration depth can reach the maximum value when the distance is 40 mm [25]. Therefore, the distances between the light