A Novel Idea of Evaluating Non-ionizing 2.45 GHz Wireless Body Area Network (WBAN) RF Radiation on Human Cognitive Performance Using Wearable Textile Monopole Antennas

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Abstract— This paper presents a novel idea of evaluating the non-ionizing 2.45 GHz Wireless Body Area Network (WBAN) radio frequency electromagnetic fields exposure effect on human cognitive performance. The study aims at determining whether exposure of non-ionizing 2.45 GHz WBAN radio electromagnetic fields (EMF) may affect the cognitive performance of human being. Twenty healthy and right-handed volunteers (10 males and 10 females) are involved in the test and exposed to 2.45 GHz WBAN, emitted by a pair of planar textile monopole antennas in 1-hr per-session, with two separate sessions; EMF exposure and sham exposure (no exposure). Paired Associates Learning (PAL) and Spatial Span Length (SSP) tasks using CANTAB eclipse version 4.0 cognitive software, are performed by each subject to assess the visual memory and working memory capacity during the exposure of on-body textile monopole (TM) antennas positioned on right-upper-arm-to-left-chest link. A total of two outcome measures are presented in measuring PAL which are PAL Total errors (adjusted) and PAL Mean errors to adjusted, measuring mean number of errors made before the stage is successfully completed. The result showed that both PAL outcome measures and SSP give no significant difference between exposure conditions (EMF and sham exposures), $p's > 0.05$. Thus, PAL and SSP performance (cognitive) is not affected by non-ionizing 2.45 GHz WBAN EMF exposure.

1. INTRODUCTION

A great concern has risen from public on the effects of radiation emitted by the communication devices due to numerous exposure of electromagnetic fields (EMF) in our daily life. It is debatable whether low-intensity EMF radiation can cause adverse health effects to human. In the open literature, many studies have been reported to examine whether radio frequency (RF) exposure emitted by mobile phone or base station may affect well-being, physiological parameters and other related human body parameters [1–6]. However, to date, the effect of non-ionizing 2.45 GHz WBAN emitted by wearable antennas on human cognitive performance has not been carried out. Thus, the main objective of the study is to investigate whether 2.45 GHz WBAN of non-ionizing exposure by wearable textile antennas in the vacinity of human body can affect human cognitive performance in terms of visual memory and working memory capacity. The study is conducted under high standard of experimental procedure, ensuring validity and important contribution to EMF effects on people's health.

2. MEASUREMENT SETUP

Twenty volunteers are involved in the study (ten are female and ten are male). Subjects are between 23 and 31 years of age (mean ± standard deviation (SD), 25 ± 2.4), and have normal body weight (BMI 19–26 $\mathrm{kg/m^2}$). The volunteers are interviewed prior to the study. This is to identify whether they are healthy and free from neurological/psychiatric history problems. The participants receive small incentives at the end of experiment sessions.

The study is conducted in an RF shielded room, Electromagnetic Hyper Sensitivity (EHS) Laboratory, Jabatan Kejuruteraan Elektrik, Politeknik Tuanku Syed Sirajuddin, Arau, Perlis, Malaysia, between May and July 2013. The dimension of the RF-shielded room is $4 \times 3 \times 2.5\,\mathrm{m^3}$. The room is furnished with one PC table with PC desktop, one sofa and a plastic armed chair. Subjects are seated on a comfortable armchair, with a distance of 40 cm from the subject's head to the PC desktop. The aim of the study is to investigate the effects of 2.45 GHz WBAN RF exposure on

human cognitive performance. The experiment consists of two sessions; RF and sham (no exposure) at 1-week intervals in a single-blinded, counterbalanced and crossover condition. CANTAB eclipse version 4.0 cognitive software by Cambridge Cognition Ltd, United Kingdom is utilized to perform the cognitve tests on subjects. Subjects spend 45–60 minutes to complete the cognitive tests (4 tasks) in each exposure session. Constant ambient light and room temperature conditions (average: 28.26 ± 0.32) are ensured throughout the whole campaign.

Two quarter-wave, omni-directional planar textile monopole antenna operating at 2.45 GHz are used as a source and receiving port, positioned parallel to the body surface (along z-direction). The total dimension of TM is 40 mm × 60 mm with a substrate thickness of 1.7 mm. A patch length, $L_M = 0.25\lambda = 30.6$ mm. The quarter-wavelength monopole has an excellent impedance matching and radiation performance in narrowband frequency [7]. A 2-port Vector Network Analyzer (VNA) (Agilent model number 5071C ENA) is used to transmit the continuous wave and receive the signal of on-body locations. RF input power supplied to TM is set to 0 dBm. Tx is fixed at the right side of upper arm while Rx is mounted on the left chest, mimicking the position of ECG sensor. Two low-loss semi-flexible Huber+Suhner coaxial cables, wrapped with microwave absorbing foam, are utilized to connect Tx with port 1 and Rx with port 2 (see Fig. 1). Antenna to body separation is 10 mm.

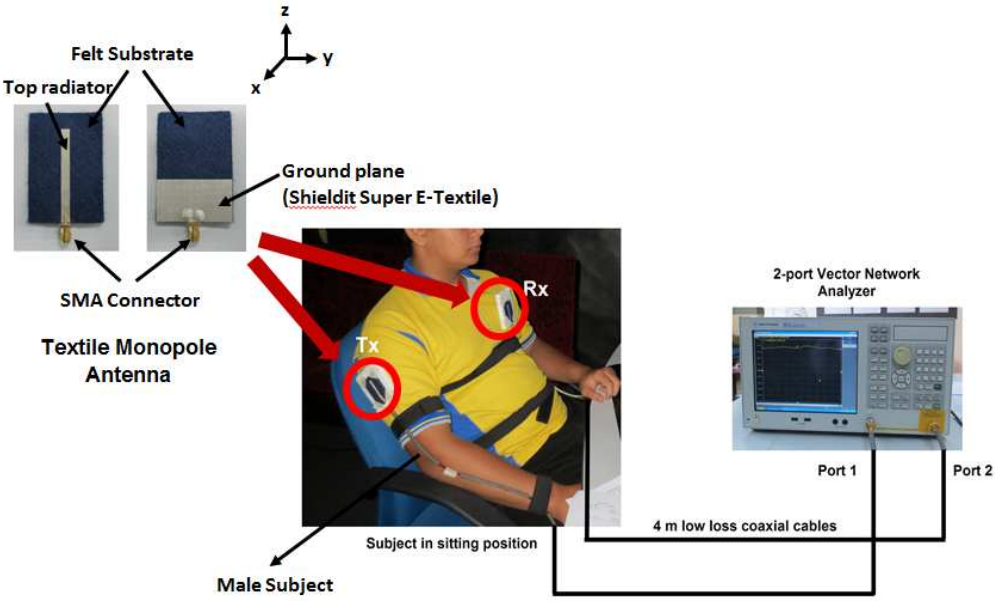

Figure 1: Measurement setup in the RF shielded room.

3. COGNITIVE TASK

We investigate the effects of wearable TM antenna RF radiation on visual memory PAL and SSP tasks using CANTAB eclipse version 4.0 cognitive software, performed by each subject to assess the visual memory and working memory capacity during the exposure of on-body textile monopole (TM). The CANTAB is a computerized neuropsychological battery that comprises 22 tests for accessing memory, attention test and excecutive function. A touchscreen computerized system that provides an accurate neuropsychological assesment and latency recording is used to test each subject. Subjects are required to memorize specific pattern locations with random assignment in the allocated boxes. If the subject makes an error, the pattern is re-presented to remind the subject of their locations. Three trials are allowable if error is made. In the clinical mode of battery test, the number of patterns increases from 1 to 8. 14 outcome measures for PAL are split into 4 groups; errors, trials, memory scores, stage completed. In this paper, two outcome measures are presented in measuring PAL in the study which are PAL Total errors (adjusted), measuring the total number of errors across all assessed problem and all stages, with an adjustment for each stage not attempted due to previous failure) and PAL Mean errors to adjusted, measuring mean number of errors made before the stage is successfully completed. Meanwhile, Spatial span (SSP) evaluates working memory capacity and the task is a visuaospatial analogue of the Digit Span test. Nine

white squares are shown in the task where some of the squares abruptly changes colour in random sequence. Subjects have to touch the white boxes on PC screen according to same order after the sequenced colour boxes disappear (clinical mode). The number of boxes varies from 2 to 9.

4. RESULTS AND DISCUSSION

We use paired sample t-test (software: SPSS version 18.0) to analyze the human cognitive performance in terms of visual memory and working memory capacity (condition: RF and Sham). The paired sample t-test reveals that there is no significant difference between mean PAL total errors (adjusted) of subjects in both conditions on 2.45 GHz ISM band field exposures [$t(19) = 0.37$, $p > 0.05$]. In the PAL mean errors to success, error increases from Sham to RF exposure condition with no significant difference [$t(19) = 0.90$, $p > 0.05$]. In contrast, there is a decrease in SSP performance between Sham and RF exposure ($p = 0.353$; Table 1]. Both conditions does not reach the maximum score 9 as the mean length, $M < 7$ in SSP. Thus, it can be concluded that PAL and SSP performances (Cognitive) are not affected by 2.45 GHz WBAN RF exposure.

Table 1: Results of cognitive performance.

Cognitive Test	**Sham**	**RF**	**Sham vs RF**
	Mean (SE)	**Mean (SE)**	***p*-value**
PAL Total errors (adjusted)	5.75 (1.50)	6.40 (1.43)	0.36
PAL Mean errors to success	1.65 (0.44)	2.05 (0.51)	0.19
SSP Span length	6.80 (0.47)	6.65 (0.40)	0.35

PAL: Paired Associated Learning, SSP: Spatial Span, SE: Standard Error.

5. CONCLUSIONS

The paper presents a novel idea of evaluating the non-ionizing 2.45 GHz Wireless Body Area Network (WBAN) radio frequency electromagnetic fields exposure effect on human cognitive performance. In the study, it is found that brain physiology is not affected by RF radiation, particularly on visual memory and working memory capacity. Further work will be conducted to thoroughly analyze the effect of 2.45 GHz WBAN RF exposure on human cognitive performance in double-blinded condition.

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