# MULTIVARIATE ASSESSMENT OF AUTOMATED MASSAGE CHAIR EFFICACY ON SKIN TISSUE PERFUSION AND SLEEP METRICS

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FACULTY OF ENGINEERING
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# MULTIVARIATE ASSESSMENT OF AUTOMATED MASSAGE CHAIR EFFICACY ON SKIN TISSUE PERFUSION AND SLEEP METRICS

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**FACULTY OF ENGINEERING**
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## ABSTRACT

Stress and sleep-related disorders are increasingly becoming more prevalent among adult population. Manual massage therapy (MMT) may assist in improving the peripheral circulation through mechanical manipulation of soft tissues and passively act upon reducing stress stimuli and in turn, may induce relaxation and sleep. For the purpose of evaluating the efficacy of massage chair therapy (MCT), this study is divided into three parts. First, a randomized controlled, cross-over, repeated measures and single-blinded trial involving 17 participants (age 21.76 ± 1.20 years; weight 52.50 ± 9.19 kg; height 163.50 ± 17.68 cm; body mass index (BMI) = 19.31 ± 1.42 $kgm^{-2}$) where skin tissue perfusion ($TP_{sk}$) measurement was taken prior and posterior to massage/control sessions. Each of the three sessions incorporating different massage modes are marked by a significant difference in skin tissue perfusion ($p<0.05$) except for control session ($p>0.05$). Furthermore, post-hoc analysis demonstrates a significant increase in $TP_{Sk}$ post-session deep tissue massage as compared to other two modes (blood circulation mode and sweet dreams mode). In the second part of the study, 6 males (age 23.33 ± 2.07 years; weight 68.42 ± 10.94 kg; height 180.30 ± 7.19 cm; body mass index (BMI) 20.92 ± 1.87) underwent MCT with only sweet dreams mode. Richards-Campbell Sleep Questionnaire (RCSQ) and wrist actigraphy were used to assess variations in sleep parameters pre- and post-session. While our evidence for effectiveness of massage in improving key sleep parameters is inconclusive, results regrading skin tissue perfusion indicate that there may potentially be positive impact of massage on circulation.



Keywords: automated massage, skin tissue perfusion, wrist actigraphy, laser doppler flowmetry.

## ABSTRAK

Tekanan dan gangguan berkaitan tidur semakin berleluasa di kalangan penduduk dewasa. Terapi urut manual (MMT) dapat membantu meningkatkan peredaran periferal melalui manipulasi mekanikal tisu lembut dan bertindak secara pasif apabila mengurangkan rangsangan tekanan dan seterusnya, boleh menyebabkan rehat dan tidur. Untuk tujuan menilai keberkesanan terapi kerusi urut (MCT), kajian ini terbahagi kepada tiga bahagian. Pertama, langkah rawak terkawal, cross-over, berulang dan percubaan membutakan tunggal yang melibatkan 17 peserta (umur 21.76 ± 1.20 tahun; berat 52.50 ± 9.19 kg; tinggi 163.50 ± 17.68 cm; indeks jisim badan (BMI) = 19.31 ± 1.42 kgm -2) di mana pengukuran perfusi tisu kulit (TPsk) dilakukan sebelum dan selepas sesi urut / kawalan. Setiap tiga sesi yang menggabungkan mod urut yang berbeza ditandai dengan perbezaan yang ketara dalam perfusi tisu kulit ($p < 0.05$) kecuali untuk sesi kawalan ($p > 0.05$). Selanjutnya, analisis post-hoc menunjukkan peningkatan ketara dalam urutan tisu dalam pasca sesi TPSk berbanding dengan dua mod lain (mod peredaran darah dan mod mimpi manis). Pada bahagian kedua kajian, 6 lelaki (berumur 23,33 ± 2,07 tahun; berat 68,42 ± 10,94 kg; tinggi 180,30 ± 7,19 cm; indeks jisim badan (BMI) 20,92 ± 1,87) menjalani MCT dengan mod mimpi yang manis sahaja. Richards-Campbell Sleep Questionnaire (RCSQ) dan aktigrafi pergelangan tangan digunakan untuk menilai variasi parameter tidur sebelum dan selepas sesi. Walaupun bukti keberkesanan urut kami dalam meningkatkan parameter tidur utama tidak dapat disimpulkan, hasil dari penyerapan tisu kulit menunjukkan bahawa ada kemungkinan kesan positif urut pada peredaran darah.

Kata kunci: urut automatik, penyerapan tisu kulit, aktigrafi pergelangan tangan, flowmetry laser doppler.

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# LIST OF SYMBOLS AND ABBREVIATIONS

| | | |
|---|---|---|
| APU | : | Arbitrary perfusion unit |
| AC | : | Alternating current |
| BMI | : | Body mass index |
| BP | : | Blood pressure |
| BCM | : | Blood Circulation mode |
| CON | : | Control mode |
| CI | : | Confidence interval |
| CV | : | Coefficient of variation |
| DBP | : | Diastolic blood pressure |
| DC | : | Direct current |
| DTM | : | Deep Tissue mode |
| ICC | : | Intraclass correlation coefficient |
| IHG | : | Isometric handgrip |
| LDF | : | Laser doppler flowmeter |
| LPST | : | Lumbopelvic stability training |
| MM | : | Manual massage |
| PPG | : | Photoplethysmography |
| PSG | : | Polysomnography |
| RCSQ | : | Richards Campbell Sleep Questionnaire |
| RBC | : | Red blood cell |
| SBP | : | Systolic blood pressure |

# LIST OF APPENDICES

# CHAPTER 1: INTRODUCTION

## 1.1 Background

According to 2017 National Health and Morbidity Survey, 29% of Malaysians have depression and anxiety disorder compared with 12% in 2011 (Awaluddin et al., 2017). Stress, induced from myriad external factors, incites vascular response from the human body; both physical and emotional stress cause significant hemodynamic alterations in the body: vasculatures regulate normal blood flow by acting as intricate conduits supplying oxygen ($O_2$) and nutrient rich blood, and removing metabolic wastes from tissues (Plante, 2002). In fact, elevated condition of stress causes higher levels of $O_2$ consumption and metabolic waste generation. Because the microcirculatory network (constituted by arterioles, capillaries, and venules) plays a vital role in replenishing tissues and recovering metabolic balance, if impaired, it can delay tissue regeneration and consequently, add to stress related complications. Unlike arteries and veins – which are regulated involuntarily through nerve impulses and/or chemical signals – lack of receptors renders the microcirculatory network unaffected from such neurogenic alterations. However, tactile stimulation on skin surface can increase arteriolar pressure and muscle temperature, and thereby, augment blood flow (Weerapong et al., 2005; Supa'at et al., 2013). In fact, massage therapy has been reported to promote local blood circulation through long manual massage strokes which compress and release the body tissues to increase blood flow to the local area (Mori et al., 2004; Heffner et al., 2012; Taspinar et al., 2013).

Several recent studies have reported that negative psychological and physiological implications of stress disorder can lead to sleep disturbances (Fan et al., 2017; Yang et al., 2011; Bernet et al., 2014), which in turn can manifest in poor quality of sleep and other health risks including death (Ramsawh et al., 2009). Coincidentally, sleep disorder corroborates with increased level of anxiety (Rafi et al., 2020). The positive effects of manual massage on sleep and anxiety disorder have been documented for different clinical groups in several studies. In one long term study involving pregnant women, researchers found that full body manual massage significantly decreased salivary cortisol and increased immunoglobulin production, thus decreasing stress and boosting immunity (Chen et al., 2017). Similarly, foot and back massage improved blood pressure (BP) and sleep quality in hypertensive women (Arslan et al., 2020). Moreover, patients from critical care, colorectal surgery, and burn units also exhibited lower levels of anxiety and better perception of sleep when their treatments were supplemented with Swedish and aromatherapy massage, respectively (Pinar & Afsar, 2015; Ghavami et al., 2019; Alves da Silva et al., 2017). Apart from these, recent studies on healthy individuals also report that massage enhances sleep quality and autonomic function by lowering cortisol levels, BP, and pulse (Malekshahi et al., 2017; Seifert et al., 2018; Ayik & Özden, 2018).

However, there remain multiple limitations in recent studies; and one such is limitation of measure. Most of the findings, especially those associated with sleep quality, have been developed on self-report measures. Furthermore, in some studies the synergistic effects of massage combined with some other therapy may have overshadowed the effects of massage alone. Moreover, due to the varied massage techniques utilized in these studies, it remains to be examined if the effectiveness of massage is associated with intensity of applied pressure on the body independent of technique. Some of these problems may be addressed through automated massage. In fact, automated massage is said to have added benefits over traditional massage: automated massage chairs always deliver consistent pressure irrespective of therapists' physical condition; the exact massage position and pressure can be precisely controlled considering an individual's body contour; and it may be more beneficial to individuals who do not like being touched by strangers and are not prone to exhaustive exertion. Despite much technological advancement on measuring apparatus, the benefits incurred from automated massage modalities have not been well explored.

## 1.2 Problem Statement

In the last decade, there have been multiple studies looking into the effectiveness of manually applied traditional massage techniques in a diverse range of sample population consisting of both healthy and hospitalized individuals. Majority of these work have been focused in understanding the possible mechanism of massage by which the reported therapeutical benefits were incurred, but there still remains a dearth of strong empirical evidence. Moreover, only a limited number of studies have reported on the physiological and physical variables with objective measurands, and to the best of our knowledge there has been no study reporting on the effects of automated massage chairs on variables such as skin tissue perfusion and sleep parameters.

## 1.3 Aim and Objectives

The aim of these experiments is to test the efficacy of the automated massage chair in regulation of tissue perfusion and its impact on the different parameters of sleep. The objectives are detailed below:

1. To design experiments techniques of massage effect measurement on tissue perfusion and sleep metrics.
2. To investigate the changes in skin tissue perfusion derived from within-subject and between-subjects measures prior to and after each experimental session.
3. To analyse and evaluate the experimental dataset.

## 1.4 Scope of Study

In accordance with the aims and objectives, this study examines the changes associated with skin tissue perfusion and sleep parameters which may manifest due to application of massage with an automated massage chair. The entire research is divided into two methodologically different protocols addressing the research objectives. The entire subject population is constituted by the students within the campus community of Univeristi Malaya, and for both study the sample population is separate. The first study encompasses a data collection and analysis period of three months and is preceded by the later study, which lasted for two months. Both studies investigate on short term changes associated with respective variables under observation. Furthermore, it should be added that while the first study does not cover observations related to enter circulatory system of the human body and second study does not discuss majorly on sleep related disorders.

## 1.5 Organization of Dissertation

This dissertation is divided into five chapters. Chapter 1 introduces and informs on background that lays the foundation for this research and delineates the purpose of this work. Next, the current state of research on massage effects involving skin tissue perfusion and sleep parameters are illustrated in Chapter 2. The following chapter outlines the protocol for both studies in a successive order. Chapter 3 also describes the participants' and apparatus details. The next chapter details the results for both studies. The first part of chapter 4 describes and disuses on the findings from the first study on skin tissue perfusion and the second part reports on the findings from the work on sleep metrics. The final chapter is chapter 5 which summarizes the outcomes from the studies, discusses on the limitations and provides suggestions on possible future directions.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Introduction

The first part of the literature review is concentrated on succinctly capturing the physiological aspects of microcirculation and its implication on the peripheral circulation. Next, different methods and modalities used for objective assessment of tissue perfusion are discussed. Additionally, findings related to massage and the microcirculation are compared and contrasted. The second part of the review discusses on constituent of human sleep and provides an overview. Furthermore, both objective as well as subjective measures of sleep assessment techniques are reviewed. Finally, the chapter is concluded on the recent findings on the impact of massage on sleep parameters.

## 2.2 Overview of Peripheral Perfusion

The two types of peripheral perfusion are referred to as muscle tissue perfusion ($TP_M$) and skin tissue perfusion ($TP_{Sk}$). In the human body, connective tissue perfusion or blood flow is regulated and controlled primarily by the central nervous system in as much as by inter-dynamics by the surrounding tissues in a given region of the body. This local tissue dynamics is representative of the state of metabolic activity related to the immediate vasculatures (Lohman et al., 2007). Additionally, reflexology of nervous control asserts that through sympathetic vasodilation and vasoconstriction, $TP_{Sk}$ may be activated involuntarily. In fact, as the vasodilator nerves are activated, they may lead to an increase in $TP_{Sk}$. This can be explained either by increased peripheral vasoconstrictor activity or impaired activity of the vasodilator system or both. Furthermore, an increase in skin temperature may be commensurate with an increase in $TP_{Sk}$. For instance, Charkoudian (2003; 2010) believes that, in response to local warming of the skin, the sensory nerve C-fibre afferents are stimulated and in turn, leads to substantial direct widening of vessels in the surrounding area of the skin. This results in an increase in $TP_{Sk}$.

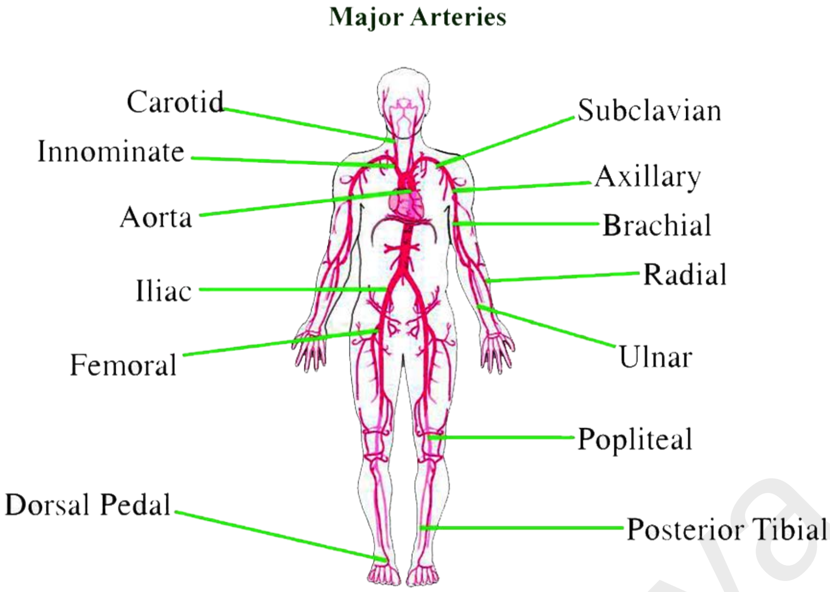



**Figure 2.1 Blood flow to-forth the upper and lower extremities and the surface of the body refers to peripheral circulation**

The microcirculatory network is primarily constituted by three types of vasculatures: arterioles, capillaries and venules. The capillaries are miniature vasculatures lined by a single layer of endothelial cells. In essence, arterioles and venules are connected through capillary beds where the exchange of oxygen and nutrients between blood vessels and tissues occur. Moreover, the microcirculation aids to maintain hydrostatic pressure through a process known as "homeostasis" at the capillary level to avoid disturbances in transcapillary exchange (Tafner et al., 2017). Furthermore, the significance of microcirculation in terms of tissue healing cannot be underestimated. As the flow of blood through the microcirculatory network increases, so too does the transport of protein, nutrients, and oxygen to the impaired tissues and as a result, tissue recovery is promoted (Lohman et al., 2011). Therefore, early symptoms of cardiovascular complications which may arise from a lack of oxygenation to tissues is reflected by changes in the microcirculation (Rossi et al., 2006). Research on patients with atherosclerosis, essential hypertension, coronary artery disease (Agarwal et al., 2012) and hyperglycaemia (Mastantuono et al., 2016) have reported that a causative factor to altercations in the microcirculation is possibly impaired dermal microcirculatory vasodilation i.e., incapability for vessel widening.

### 2.3 Peripheral tissue perfusion assessment

Measuring the flow of blood underneath the skin is widely conducted through evaluating either of these three parameters either individually or together: transport of heat, oxygenation level and physical movement by the red blood cells. In fact, assessing for heat transport and oxygen content in dermal tissue perfusion are remarkably useful non-invasive means of assessing for peripheral circulation because red blood cells due to are capable of carrying oxygen molecules by binding with haemoglobin which also known as oxyhaemoglobin. Experientially, there exist a range of modalities that can be used to assess microcirculation such as doppler ultrasound, photoplethysmography, near infrared thermography, and laser doppler flowmetry (Swain & Grant, 1989).

#### 2.3.1 Doppler Ultrasound

Based on the principle of "Doppler Effect", the ultrasound machine enumerates and constructs real-time images of vascular flow of blood. Ultrasounds are a product of high frequency wave generated and modulated through matter by means of piezoelectric effect. A transducer generates and modulates these ultrasonic waves and are emitted on and through the surface of the skin tissue. As the wave propagates through the dermal layers, it penetrates, refracts, but largely, is reflected back upon hitting the red blood cells flowing within the vasculature. This reflected energy is then picked up by the same or different transducer and consequently produces real-time images that depicts skin tissue perfusion. Theoretically, the frequency of the reflected wave is proportional to the velocity of the red blood cells. Multiple types of doppler ultrasound techniques exists, inclusive of which are continuous wave Doppler, pulsed Doppler, spectral Doppler, colour Doppler and power Doppler (Shung, 2015). However, unless operated by a trained individual the relatively high viability of reliability and reproducibility may be diminished (Kubli et al., 2000). Indeed, clinical usage of doppler ultrasound incorporates examination of blood flow through deeper arteries, possible implications can form resulting in obscuring of imaging because of immobile tissues such as bones or other denser tissues. Therefore, effects linked to skin tissue perfusion may be overestimated.

### 2.3.2 Photoplethysmography

Photoplethysmography (PPG) is a non-invasive modality for measuring skin tissue perfusion. The PPG continuously emits light through a fibre optic and simultaneously records light that is scattered back. The light source is directed towards the skin and light which is reflected back after collision with red blood cells is collected by a photodetector. Theoretically, higher number of red blood cells is marked by higher concentration of haemoglobin content. In fact, larger contents of haemoglobin scatters and reflect higher degree of light which is detector. Therefore, alterations in the photoreactor signal are proportional to changes in the blood flow and blood volume of the immediate underlying tissue. The optical signal detected by the photodetector can be separated into a direct current (DC) component and an alternating current (AC) component. The DC component of the signal reflects variations related to changes in total blood volume of the examined tissue. On the other hand, the AC component reflects the pulsatile pressure, pulsatile blood flow, pulsatile blood volume and the number of blood vessels in the immediate tissue under examination (Hagblad et al., 2010). The use of near-infrared laser light and photodetector renders the PPG comparatively simple in architecture and cost-efficient means to examine tissue perfusion (Berardesca et al., 2002). However, due to an absence of proper mechanical coupling with the skin tissue, the signal generated from PPG can have poor tolerance level and appear distorted under motion (Sun & Thakor, 2015).

### 2.3.3 Laser doppler flowmetry

Another optical technique which can non-invasively assess for skin tissue perfusion is the laser doppler flowmeter (LDF). An optical source capable of producing single or multipoint laser light is attached on the skin and subsequently a beam of laser is emitted. Based on the principle of "Doppler Effect", and similar to the ultrasound, the penetrating light is scattered as it collides with mobile red blood cells (RBC) within tissue vasculature. Naturally, this backscattered light is phase-shifted with proportion to the velocity of RBCs. Next, doppler shifted light is detected by a photodetector. The doppler shift implies alteration is frequency and therefore, wavelength of the corresponding light detected. Again, the amount by which the light wavelength alters is directly proportional to the quantity and mean velocity of the RBCs in the blood volume sample under observation. Skin tissue perfusion ($TP_{Sk}$) is therefore, a product of mean velocity and quantity of RBCs. Consequently, this provides LDF with the capability to provide not only axial blood flow, but also a perfusion measure for the entire tissue volume.

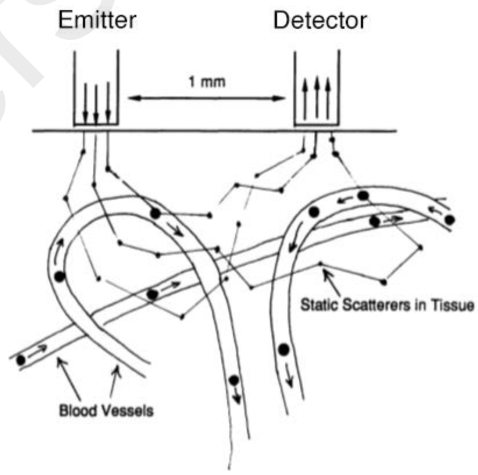



**Figure 2.2 LDF probe emitting and detecting back-scattered light from RBCs in vascularized tissue (Adapted from Nilsson, 1990)**

The skin is divided into multiple layers and majority of interaction between light and tissue occurs at the epithelial or outermost layer of the skin. Upon emission, some of the coherent monochromatic light is scattered from the stratum corneum upon impact. As the light penetrates deeper into the dermal layers (1 -1.5 mm), it is absorbed by melanin and scattered by RBCs. This is due to the deeper dermis being populated with the entire horizontal plexus with its arterioles, capillaries and postcapillary venules. However, the deep horizontal plexus at the subcutaneous dermal junction cannot be not measured (Abdulhameed et al., 2019). Therefore, rendering the measurement from LDF limited to a relatively small tissue volume. As a result, in terms of raw LDF signal, there exists not only site-to-site but also periodical heterogeneity in an individual measurement basis. Therefore, as part of a process to normalize the reading, the instrumentation applies a percentage change from a physiological zero (32°C), which is the temperature felt by the skin. This temperature is regarded neither warm nor cold. Therefore, unless a possible arterial occlusion is present, the chances of divergence of the percent change from the thermoneutral baseline (33°C -34°C) is improbable. Alternatively, similar changes can be brought about by local heating of the endothelium through heating or by means of elevated local skin tissue perfusion or both (Low et al., 2020).

## 2.4 Effect of massage on skin tissue perfusion

Massage therapy is a systematic manipulation of soft tissues with rhythmical pressure and stroking (Field, 1998). Massage targets soft tissue such as muscles, tendons and facias. In fact, massage techniques had been in practice in many cultures throughout human history as a means to address such disorders (Ernst, 2003). Traditionally, however, while generally accepted and appreciated, manual massage has largely been considered a companion treatment rather than a therapeutic intervention per se. Conventionally, manually applied massage is imparted on the body as the masseuse or physiotherapist performs several manoeuvres including effleurage, kneading, static or slide pressures, but also light and deep pressures. Furthermore, there exist different types of massage techniques such as Swedish massage, petrissage and effleurage, Chinese acupressure technique and so on. These techniques are likely to involve biomechanical, physiological, neurological and psychological mechanisms, although the empirical attributions are not always confirmed by scientific data (Weerapong et al., 2005). At the same time, there is a rise in public interest on the automated variants of massage, particularly massage chairs. Massage chairs are electrically operated devices integrated with airbags, rollers and other complex mechanical apparatus and are capable of exerting forces in the form of tapping and kneading on acupressure points with minimal intervention from human operator. A combination of retroactive and proactive mode of control thus makes automated massage chair a viable therapy alternative provided that its effectiveness is akin to that of conventionally applied manual massage.

Massage therapy has been reported to promote local blood circulation. With application of long massage strokes in a compressive-release alternating fashion, increased flow to limb was observed by Supa'At et al. (2013). Another study by Mori et al. (2004) noticed that post-exercise massage in athletes were marked by a decrease is not only the subjective measure of fatigue captured using a visual analogue scale (VAS), but also an increase in perfusion rate and total perfusion volume. The authors suggested that massage may had aided in increasing the removal of metabolic waste and subsequently increase levels of perfusion. However, another study investigating the effects of massage on femoral arterial blood flow, concluded that post exercise massage only assisted in delivering a smaller segment of the total flow to the microcirculatory bed, which in turn facilitated the absorption of metabolic waste and lactate removal, but to a limited effect (Hinds et al., 2004). In a comparative longitudinal study between massage and Matrix Rhythm therapy on peripheral circulation, Taspinar et al. (2013) showed that a greater degree of haemodynamic alteration was present when manual massage was combined together with Matrix Rhythm therapy rather than either therapy applied in isolation. The authors assume that the combined therapy induces tonic vibration reflex which in turn assist in active muscle contraction and therefore, cause an increase in blood supply to the limbs. It is speculated that when massage is applied to part of the body, the tissue in the immediate region is stimulated, resulting in a rise in local temperature. This also increases the transport of nutrients and oxygen to that tissue region (Portillo-Soto et al., 2014). In another combinational therapy of massage as an adjunct to lumbopelvic stability training (LPST), the authors reported that a significant decrease in pain variables were associated with the removal of accumulated lactic acid in the lumbar muscle and thus reduction in lower back pain (Joseph et al. 2018). Additionally, a number of studies on their findings of the impact of massage on peripheral circulation, particularly skin tissue perfusion is detailed in Table 2.1.

**Table 2.1 Effect of massage on skin tissue perfusion**

| Author (year) | Study Design | Sample | Groups | Intervention | | | | Outcome measures | Effects |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Massage instrument | Targeted area | Technique | Time | | |
| Mori et al. (2004) | RT | 29 males | NR | MM | Lower back | NR | Single session; 3 repeated loading with 60s interval; 5 mins/session | $TP_{Sk}$ & skin temperature | Massage vs rest: significant $TP_{Sk}$ ↑ & temperature ↑ |
| Hinds et al. (2004) | RCT | 13 males | 2 groups: EG & CON | MM | Lower limbs | effleurage & pétrissage | Single session; 2 × 6 mins bouts/session. 1 min rest between bouts | $TP_{Sk}$ & skin temperature | EG vs CON: significant $TP_{Sk}$ ↑ & temperature ↑ |
| Tochikobu et al. (2006) | RT | 19 males & 36 females | NR | PSACM | Lower limbs | N/A | 2 × 15 mins bouts/session; 15 mins rest between bouts | Peripheral perfusion | Significant peripheral perfusion ↑ |
| Taspinar et al. (2013) | RT | 15 females | 2 groups: EG 1: MRT EG 2: MM | NR | Lower extremity | NR | 2 sessions: 30 mins/session; session interval NR | Via DUS: Blood velocity, artery diameter and blood flow | EG1 & EG2: significant ↑ in tibial & popliteal artery. |
| Portillo-Soto et al. (2014) | RCT | 14 males & 14 females | 3 groups: EG 1: GT EG 2: MM CON | NR | Lower limb | NR | Single session; 10 mins/session | Skin temperature | Significant ↑ temperature in EG1 vs CON & EG2 vs CON |

Table 2.1 (continued)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Joseph et al. (2018) | RT | 16 female athletes with chronic backpain | 2 groups: EG1: LPST + MM EG2: MM | NR | Lower back | NR | 3 sessions; 20 mins/session | $TP_{Sk}$ | Significant ↑ in EG1 vs EG2 |
| Wiltshire et al. (2010) | RT | 20 males | NR | NR | Upper limb | effleurage & pe´trissage | Single session; 10mins/session | Via DUS: Forearm blood flow | Forearm blood flow ↑ |
| Lohman et al. (2007) | RT | 23 males & 22 females | 3 groups: EG1: vibration EG2: exercise EG3: vibration + excersie | Vibration massage | Lower limb | NR | NR | Via LDF: $TP_{Sk}$ | EG1 significant ↑ vs EG2 & EG3 |
| Castro-Sánchez et al. (2011) | RT | 40 males & 58 females | 2 groups: EG & placebo | magnetotherapy equipment | Feet | NR | 15 weeks. 2 sessions/week; 1 hour/session | Via PPG: $TP_{Sk}$ | Significant ↑ in EG vs placebo |

↑: increased; ↓: reduced; RT = randomised trial; RCT: Randomised controlled trial; CON: Control; EG: Experimental; MM: manual massage; NR: not reported; NS: not significant; $TP_{Sk}$: skin tissue perfusion; PSACM: pulse synchronised air cuff massage; N/A: not applicable; MRT: matrix rhythm therapy; DUS: Doppler ultrasonography'; GT: Graston Technique; LPST: lumbopelvic stability training; LDV: laser doppler velocimetry; PPG: photoplethysmography

## 2.5 Overview of Sleep

Sleep may be referred to as state when the human body remains minimally active for a considerably long duration of time. As a result, the body's responsiveness to external stimuli is reduced. In fact, the body has to navigate between sleep and wakefulness in order to recuperate itself and the process are reversible. The circadian rhythm and the homeostatic system are the two primordial internal biological regulators of Sleep. The circadian rhythm is responsible for coordination of physiological and behavioural activities such as sleeping, waking and eating. Additionally, environmental alterations induced by either sunlight or surrounding temperature also significantly affects the body's circadian rhythm (Frahud & Aryan, 2018). On the other hand, the homeostatic system plays an active role in generating and accumulating hypogenic or sleep-inducing compounds, which in turn dictates the human body's urge to go to sleep (Eidelman, 2002).

Sleep can be categorised into two main types: (i) rapid eye movement (REM) sleep and (ii) non-rapid eye movement sleep (NREM). NREM can be further broken down to multiple stages. Each type of sleep is associated with specific brain wave characteristics, body and neuronal activity (Moorcroft, 2013). Progression of sleep is constituted by a series of four or five sleep cycles. Moreover, each cycle alternates between periods of NREM sleep stages and REM sleep. A typical sleep cycle follows the stages from NREM stage 1 to NREM stage 3/4 and finally into REM sleep. The concluding part of the sleep cycle is also known as deep sleep (Moorcroft, 2013). In progression of sleep, a person transitions from NREM sleep to REM sleep, where stages gradually become longer and deeper states of sleep. Unless a stronger external stimulus is provided, a person in deeper states of sleep cannot be awakened. REM sleep is also associated with more experience of dreaming (Moorcroft, 2013). Different stages of sleep can further be distinguished by alteration in physiological parameters. It has been observed that heart rate variability (HRV), respiration rate and eye movements increase (Moorcroft, 2013), and body movement activity and body temperature gradually decrease as the individual in sleep progresses towards REM sleep (Wilde-Frenz & Schulz, 1983). Quantitative assessment towards evaluating the alterations in physiological variables and motor activities have been accumulated in decades of research establishing parameters for sleep assessment: distinguishing sleep stages (Wilde-Frenz & Schulz, 1983), assessing sleep quality (Cohrs et al., 2001), and detecting sleep disorders (Allena et al., 2009), which are detailed in the following section.

## 2.6 Metrics for Sleep Assessment

Quality of sleep directly impacts the productivity of an individual on a daily basis. Typically, with progression of a day, the body wanes into psychological and physical fatigue caused by work and exertion. With a good quality of sleep the body is able to recover and rejuvenate. Alternatively, sleeplessness or poor quality of sleep negatively impacts the body making an individual perpetually exhausted and wanting. As a result, the ability for physical activity is affected marked by, for instance, a lack of energy. This in turn leads to a major drop in performance. Furthermore, impaired sleep tips the body homeostasis causing myriad afflictions such as anxiety, apnoea, insomnia, and many more diseases (Ohayon et al., 2017). Additionally, numerous environmental factors and personal habits can impact the quality of an individual's sleep. For instance, research investigating the effects of smoking on sleep report that nicotinic substance containing acetylcholine stimulates and activates neurons in gigantocellular tegmental field of the brain, thus reducing and inhibiting non-REM sleep (Jaehne et al. 2012).

As outlined by the national sleep foundation [58], there are twelve indicators to assess quality of sleep: (i) REM (ratio of sleep spent in rapid eye movement to total sleep time), (ii) N1 sleep (ratio of sleep spent in non-REM stage 1 to total sleep time), (iii) N2 sleep (ratio of sleep spent in non-REM stage 2 to total sleep time), (iv) N3 sleep (ratio of sleep spent in non-REM stage 3 to total sleep time), (v) sleep efficiency (ratio of sleep-to-sleep time in bed), (vi) awakenings (number of episodes in which individual is awake for more than 5 minutes), (vii) wake-time after sleep onset (amount of time spent awake when sleep is initiated and before final awakening), (viii) sleep latency (the time it takes to transition from wake to sleep), (ix) nap count (number of naps per 24 hours), (x) nap duration (average length of each nap), (xi) nap frequency (how often the nap occurs), and (xii) arousals (going from deeper stage to lighter stage of sleep, or from REM to wakefulness).

## 2.7 Sleep Assessment Devices

### 2.7.1 Polysomnography

Polysomnography (PSG) and Actigraphy are the most popular means of objectively measuring sleep in the field of medicine. Screening for possible sleep disorders is generally conducted overnight in a laboratory-based PSG system. In fact, PSG is considered as the most reliable method for assessing sleep (Sheldon, 2005). Clinically when monitoring sleep, PSG is used to quantify the alterations taking place during sleep. Medical technologist or trained personnel is usually in charge of conducting the study and remains present throughout the entire duration of the study. The technician will be responsible for setting up the equipment, placing electrodes and sensors on the patient's body (scalp, temples, chest, legs), and monitoring the study over the course of the night. The sensors can include nasal pressure sensors, respiratory inductance plethysmography (RIP) belts, microphones or even pulse oximeters. A basic PSG system will involve multiple recording in a single session: brain activity using electroencephalogram (EEG), muscle activity using electromyogram (EMG), and eye movements using electrooculogram (EOG) (Howard, 2004). In addition to these, physiological variables recorded are respiratory effort, airflow, blood oxygen levels and heart rate. Alternatively, a portable version of PSG is also present to conduct assessment at a non-clinical premise. As compared to clinical settings, patient likeability to portable PSG device is further aggregated due to its relatively less expensive price and connivence to be operated at home. However, the diagnostic benefits of portable PSG devices can be greatly minimized in the scenarios whereby there remains inability for clinicians to directly monitor patient behaviour, solve to remediate technical issues, and/or control recording and setup conditions (Sheldon, 2005).

### 2.7.2 Actigraphy

Unlike a PSG which is a bulk apparatus, an Actigraph is an instrument that can be worn on the wrist, ankle or hip with the aid of a belt and provides continuous capability for measuring sleep parameters. In fact, some actigraph devices are created with additional functionality to mark and highlight specific and unique occurrences such as waking up from bed or lights on/off events. Usually worn on the non-dominant wrist, an actigraph enables physician to track patient's movement activity for longer periods and thus sleeping patterns (Howard, 2004). The actigraph hosts an accelerometer as its principal component which is sensitive to movements in any spatial directions. Unique algorithms are then used to construct valuable information such as different kind of sleeping metrics: sleep efficiency, wake-time after sleep onset, total sleep time and sleep onset latency. Studies investigating sleep disturbances and variability in circadian rhythm have also incorporated actigraph devices (Howard, 2004).



## 2.8 Effect of massage on sleep

Evaluation of the effect of massage has been the focus of multiples studies of the last decades which involve healthy subjects as well as patients from cardiac, oncology, renal, surgery and intensive care units. A study on career women spanning for 4 weeks by Kao et al. (2017), the researchers found that acupressure massage led to significant improvement in overall quality of sleep in participants. However, another study sought to study the effect of aromatherapy combined with traditional massage on healthy subjects and found that there were no significant changes post-intervention as reported by PSQI (Pittsburgh Sleep Quality Index).

Patients undergoing colorectal surgery were reported to benefit from preoperative massage in a study by Ayik & Özden (2018). In this study, a randomised allocation of patients was made into 2 groups – pre-surgery morning and post-surgery evening – where patients received back massage for 10 minutes. The treatment group showed improved levels of sleep and decreased anxiety compared to control group. Similar findings have been reported for patients in cardiac and intensive care units. Cheraghbeigi et al. (2019) reported that in their study involving 150 cardiac patients, there was a significant improvement in sleep quality in both aromatherapy and massage group compared to control group. Additionally, the authors reported that aromatherapy alone was more effective than massage. Patients in this study received massage for 1 week each night. Another controlled study by Hsu et al. (2019) showed that 3 sessions of massage may improve the total sleeping time of ICU patients; however, in their study, while mean total sleep time is 5 hours as recorded on Actigraph device, observed mean sleep time reported by attending nurses were significantly low at 3.59 hours. Sleep deprivation and sleep related disorders are not uncommon in coronary care units. In a quasi-experimental study assessing the effect of reflexology and massage on cardiac patients, participants were divided into three groups: reflexology massage, foot bath and combination of both reflexology and foot bath (Rahmani et al., 2016). They found that a greater reduction of sleep disturbance was reported in patients receiving combined therapy than massage alone.

Moreover, studies with postpartum, cancer and haemodialysis patients have been conducted for evaluating the effects of massage on sleep. It should be noted that almost all studies involved subjective measures of sleep. These are detailed further in table 2.2.

**Table 2.2 Effect of massage on sleep**

| Author (year) | Study Design | Sample size | Groups | Protocol | | | | Outcome measures | Effects |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Massage instrument | Targeted area | Technique | Time | | |
| Kashani et al. (2014) | RCT | Breast cancer patients: 57 women | 2 groups:<br>1. EG<br>2. CON | MM, researcher | Spine, shoulder, upper and lower limbs | Effleurage | 4 weeks. 3 sessions/week, 20 mins/session | PSQI | Significant: EG vs CON |
| Ko & Lee (2014) | RCT | Postpartum women: 60 | 2 groups:<br>1. EG<br>2. CON | MM, trained therapist | Back | NR | 5 sessions, 20 mins/session | PSQI | Significant: EG vs CON |
| Rahmani et al. (2016) | Quasi-experimental | Cardiac patients: 140 | 4 groups:<br>EG 1: reflexology<br>EG 2: bath<br>EG 3: reflexology + bath<br>CON | MM | Foot | NR | 2 sessions, 10 mins/session | VSH | Significant: EG 1 & EG 2<br>NS: EG 3 & CON |
| Unal & Akpinar (2016) | RCT | Haemodialysis patient: 105 | 3 groups:<br>EG 1: reflexology<br>EG 2: massage<br>CON | MM | Foot & back | Effleurage, petrissage & friction | 4 weeks. 2 sessions/week | PSQI | Significant: EG 1 & EG 2<br>NS: CON |

Table 2.2 (continued)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Chang et al. (2017) | RCT | 50 healthy subjects | 2 groups:<br>1. EG<br>2. CON | MM, trained therapist | Head, shoulder & neck | NR (aromatherapy + massage) | 4 sessions.<br>1 session/week | PSQI | PSQI: NS |
| Kao et al. (2017) | RCT | Healthy women: 132 | 4 groups:<br>1. Placebo<br>2. AT 1 (lavender oil)<br>3. AT 2 (blended oil)<br>4. MM | MM, trained physician | 17 Acupressure points | Traditional Chinese massage | 4 weeks.<br>AT: 3 sessions/week, 20 mins/session<br>MM: | PSQI | Significant: all groups (PSQI ↓) |
| Ayik & Özden (2018) | RCT | Colorectal surgery patients:<br>EG = 40<br>CON = 40 | 2 groups:<br>1. EG<br>2. CON | MM, researcher | Back | NR | 2 sessions, 10 mins/session | RCSQ | Significant: EG vs CON |
| Cheraghbeigi et al. (2019) | RCT | Cardiac patients: 150 | 3 groups:<br>1. CON<br>2. AT<br>3. MM | MM | Upper and lower limbs | NR | 7 sessions each night | PSQI | Significant: AT vs CON; MM vs CON;<br>NS: AT vs MM |

Table 2.2 (continued)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Rafii et al. (2019) | Quasi-experimental | Burn patients: 105 | 3 groups: 1. CON 2. Placebo 3. EG | MM, physiotherapist | Heathy unburnt skin | NR (AT + MM) | 3 sessions/ week, 20 mins/session | PSQI | Significant: EG (PSQI ↓) vs CON |
| Hsu et al. (2019) | Qusi-experimental | ICU patients: EG = 30 CON = 30 | 2 groups: 1. EG 2. CON | MM | back | NR | 3 sessions/ night, 10 mins/session | 1. VSH 2. Sleep time: (i) observed (ii) actigraph | Significant: 1. VSH ↓ 2. observed sleep time ↓ 3. actigraph sleep time ↑ |
| Arslan et al. (2020) | RCT | 90 patients: EG = 60 CON = 30 | 2 groups: 1. EG 2. CON | MM | foot and back | NR | 6 sessions 2 sessions / week, 30 mins/session | 1. PSQI 2. SBP & DBP | Significant: 1. PSQI ↓ 2. SBP ↓ 3. DBP ↓ |

↑: increased; ↓: reduced; RCT: Randomised controlled trial; CON: Control; EG: Experimental; MM: manual massage; PSQI = Pittsburgh Sleep Quality Index; SBP: systolic blood pressure; DBP: diastolic blood pressure; NR: not reported; ICU: intensive care unit; VSH: Verran and Snyder-Halpern Sleep Scale; NS: not significant; RCSQ: Richard-Campbell Sleep Questionnaire; AT = aromatherapy.

# CHAPTER 3: METHODOLOGY

## 3.1 Investigating effects of automated massage on skin tissue perfusion

### 3.1.1 Participants

17 subjects (age 21.76 ± 1.20 years; weight 52.50 ± 9.19 kg; height 163.50 ± 17.68 cm; body mass index (BMI) = 19.31 ± 1.42 $kgm^{-2}$) who met the inclusion and exclusion criteria were recruited and completed the study. The study was approved by Universiti Malaya Research Ethics Committee under the reference no. UM. TNC2/UMREC – 991, a copy is provided in Appendix A. Inclusion criteria: (a) having a BMI within the range of 18 and 24.5 $kgm^{-2}$, and (b) adult within the age group of 18 to 30 years. Exclusion criteria: (a) low tolerance to pain from massage induced pressure; (b) pregnant or on menstruation; (c) history of cardiovascular disease, musculoskeletal disorders, skin diseases, hormonal diseases, depression and mental disorders; (d) suffering from chronic pain or operative or non-operative injuries such as chronic back or lower limb pain/injury; and (f) accustomed to smoking and consumption of alcohol. Recruitment for participants were carried out by online email invitation. At the onset of the study, after recruitment, each participant was instructed on the study protocol orally, and asked for both written and oral consent, the form for which is provided in Appendix A.

### 3.1.2 Procedure

The study was randomized controlled, single-blinded, repeated measures and cross-over by design. Each participant was scheduled to four sessions on four separate days; and all were crossed-over across the sessions after 24-hour wash-out period with each individual acting as their own control. Participants during massage session underwent a pre-programmed massage mode for 30 minutes, whereas during the control session, they were instructed to sit on the massage chair without having the massage shown in Figure 3.1. In both conditions, participants were asked to minimize their movements and refrain from falling asleep. All subjects were asked to have enough sleep and not to consume any drinks containing caffeine 12 hours prior to the sessions. During each visit, participants were instructed to rest on the massage chair for 15 minutes to acclimatize. Afterwards, their blood pressures (BP) were recorded. Skin tissue perfusion ($TP_{Sk}$) was recorded for 5 minutes pre- and post-experiment, respectively. During the measurement, participants were requested to refrain from talking, falling asleep and making excessive body movements. Also, an ambient temperature of approx. 25 was maintained during the sessions.

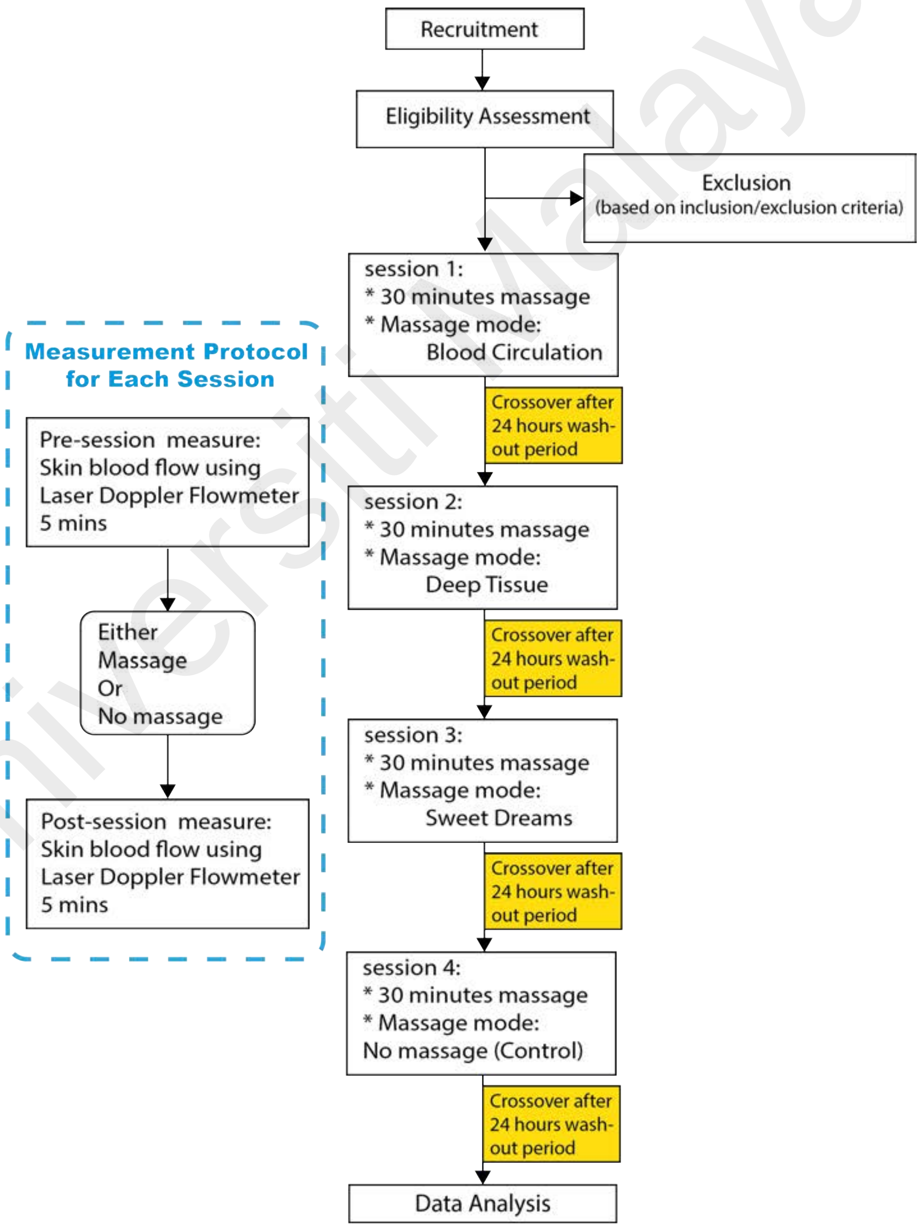


**Figure 3.1 Experimental protocol for the study investigating effect of massage on skin tissue perfusion**

### 3.1.3 Apparatus and Outcome Measurements

#### 3.1.3.1 Massage chair configuration

The OGAWA Master Drive AI Massage Chair (Ogawa World Bhd.) was used for delivering massage to the participants. Three pre-programmed massage modes used in the study – "blood circulation", "deep tissue", and "sweet dreams" – are combination of rolling, kneading and shiatsu techniques with varying levels of intensities. The massage positions and acupressure points, targeting various muscle groups, are indicated with reference to traditional Chinese massage techniques as seen in figure 3.2; and mechanical tools embedded within the massage chair consisting of rollers, airbags and heaters function in a programmed fashion to deliver the different types of massage. A more detailed illustration of the massage chair is provided in Appendix C.

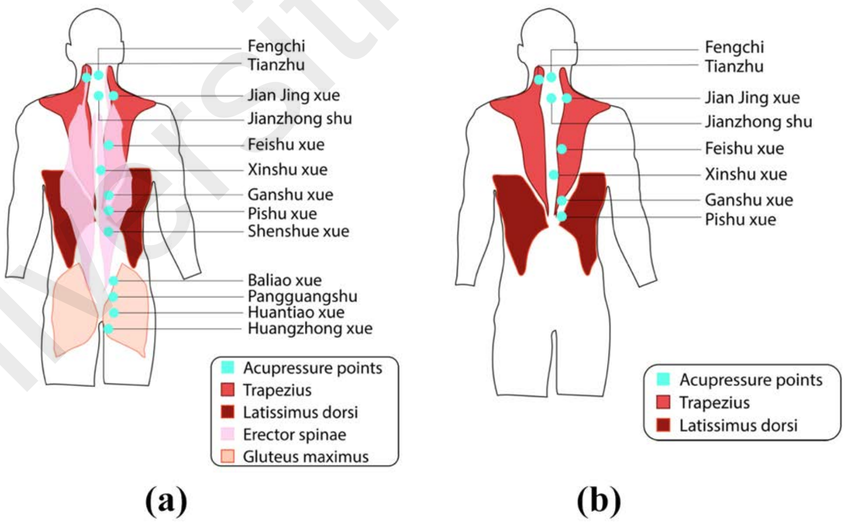
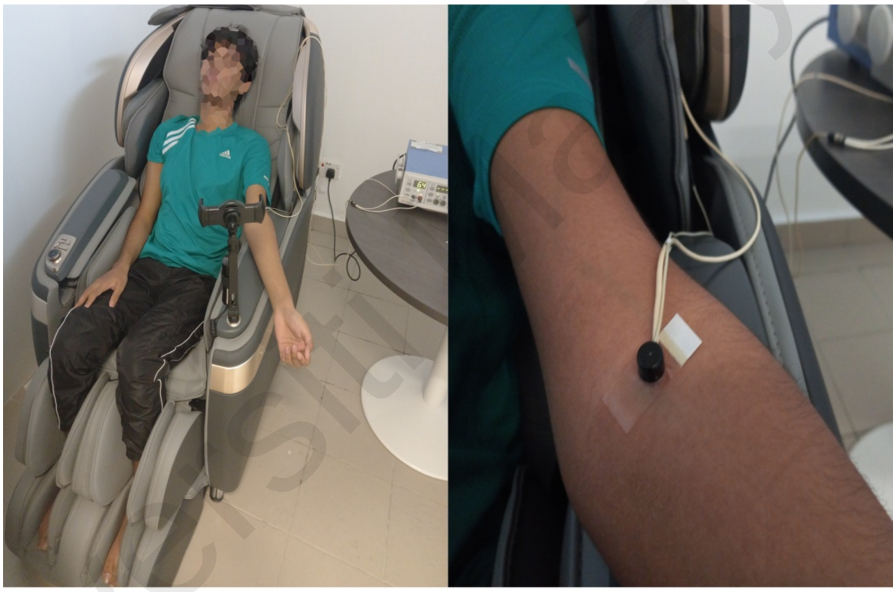



**Figure 3.2 Acupressure points and associated muscle group targeted by the massage modes - (a) Blood Circulation and Deep Tissue, (b) Sweet Dreams**

#### 3.1.3.2 Blood Pressure

The blood pressure (BP) was measured with a Colin Press Mate BP 8800P NIBP Blood Pressure Monitor (Colin Europe, Courbevoie, France). The measurement of BP preceded the measurement of pre-massage skin tissue perfusion. Participants were instructed to remain seated on the massage chair at the end of the acclimatization period and the BP air cuff was attached to their non-dominant arm, which was at heart level. The measurement of BP was conducted to verify that the healthy participants had properly acclimatized, which was indicated by their systolic and diastolic blood pressure levels. 3 consecutive measurements of BP were taken and from these readings the participant's mean BP was calculated. A systolic pressure reading in the range of 115 to 125 mmHg and a diastolic reading in the range of 75 to 85 mmHg was considered to be normal and therefore, accepted to proceed with the rest of the session.



(a) (b)

**Figure 3.3 (a) Participant being measured for $TP_{Sk}$ using LDF (b) LDF optical probe placed on the antecubital fossa region of the participant's forearm**

#### 3.1.3.3 Skin Tissue Perfusion

The skin tissue perfusion ($TP_{Sk}$) was measured with a single-point laser Doppler flow meter (Periflux System 5000, Perimed, Järfälla, Sweden). The unit of measurement does not conform to any particular system and is regarded as Arbitrary Perfusion Unit (APU). The subject was seated in a reclined supine position with their non-dominant forearm slightly abducted and resting on the armrest of the massage chair shown in figure 3.3 (a). The single point optic fibre was placed on the anterior cubital fossa region as shown in figure 3.3(b). The superficial dermis of the antecubital fossa region, which is marked by a depression on the elbow, was first cleaned with a clean adhesive tape and then wiped off with alcohol pad before attaching a 2-sided transparent adhesive tape on the site. Next, the optical fibre probe was placed carefully and attached over the other side of the tape. The position was marked for post-intervention remeasurement of $TP_{Sk}$. The $TP_{Sk}$ was recorded twice each session: 5 minutes before and 5 minutes after measurement. The collected $TP_{Sk}$ readings were further sampled at 5 seconds interval before analysing with statistical software. The raw data for all session measurement is provided in Appendix B.

### 3.1.4 Statistical Analysis

The statistical analysis was performed with the IBM Statistical Package for the Social Sciences (SPSS) (version 25.0, SPSS Inc., Chicago IL, USA). First, the sampled $TP_{Sk}$ data were checked for normal distribution. The Shapiro-Wilk test confirmed that the normal distribution is absent in the data. Thereafter, difference between the measured variable in all four sessions were compared and presented as means together with standard deviation. Additionally, percent change in each session before and after respective intervention was also calculated. In order to assess for both degree of correlation and agreement between the measured variables within the same session, the intraclass correlation coefficient (ICC) as well as coefficient of variation (CV) were calculated. The ICC was calculated for single measurement, absolute-agreement, two-way mixed effect model for each session. While there are no standard values for acceptable reliability using the ICC, researchers have suggested of ranges of ICC values indicating reliability for purpose of interpretation: less than 0.5, poor; between 0.5 and 0.75, moderate; between 0.75 and 0.9, good; and greater than 0.90, excellent (Koo & Lee, 2016; Wier J. P., 2018). In addition, the CV was calculated to assess the level dispersion in measured $TP_{Sk}$ values within the same session and presented as percentage of the ratio of standard deviation and overall mean. A small value of CV was indicative of greater reliability and smaller variability within the same session (Lackner et al., 2005). On the other hand, one-way analysis of variance (ANOVA) was performed with a significance level of $p < 0.05$ to assess for the between-sessions difference between any two of the four sessions separately. Finally, Bland Altman graphs were constructed by plotting the mean of the difference of pre- and post-intervention measures of $TP_{Sk}$ against the difference between the post- and pre-intervention $TP_{Sk}$ values to assess for between-session repeatability and difference.

## 3.2 Investigating effects of automated massage on sleep metrics

### 3.2.1 Participants

6 males (age 23.33 ± 2.07 years; weight 68.42 ± 10.94 kg; height 180.30 ± 7.19 cm; body mass index (BMI) 20.92 ± 1.87) participated for the experimental procedures. Percipient selection was made based on the similar set of inclusion-exclusion criteria stated in section 3.2.1. The study was approved by Universiti Malaya Research Ethics Committee under the reference no. UM. TNC2/UMREC - 991.

### 3.2.2 Procedure

Initially, the recruited participants were instructed on the experimental protocol. On the day before the first experimental session, they were asked to wear an Actigraph device for 24 hours. Before commencing the massage sessions, their informed consents were obtained. Afterwards, participants underwent a single massage session every day for three consecutive days. Each participant wore an Actigraph GT9X Link on their non-dominant wrist 24 hours after massage session for the duration of the entire study period, to monitor their sleep pattern. The Actigraph was taken off only during massage session, and bathing to avoid damage from water. The compliance for wearing the GT9X Link was set to minimum of 18 hours/day. The participants had to complete a sleep questionnaire twice: at the beginning, and on the following day at the end of their three-day massage period.

During the study period, participants were asked not to take antidepressants and caffeinated drinks.

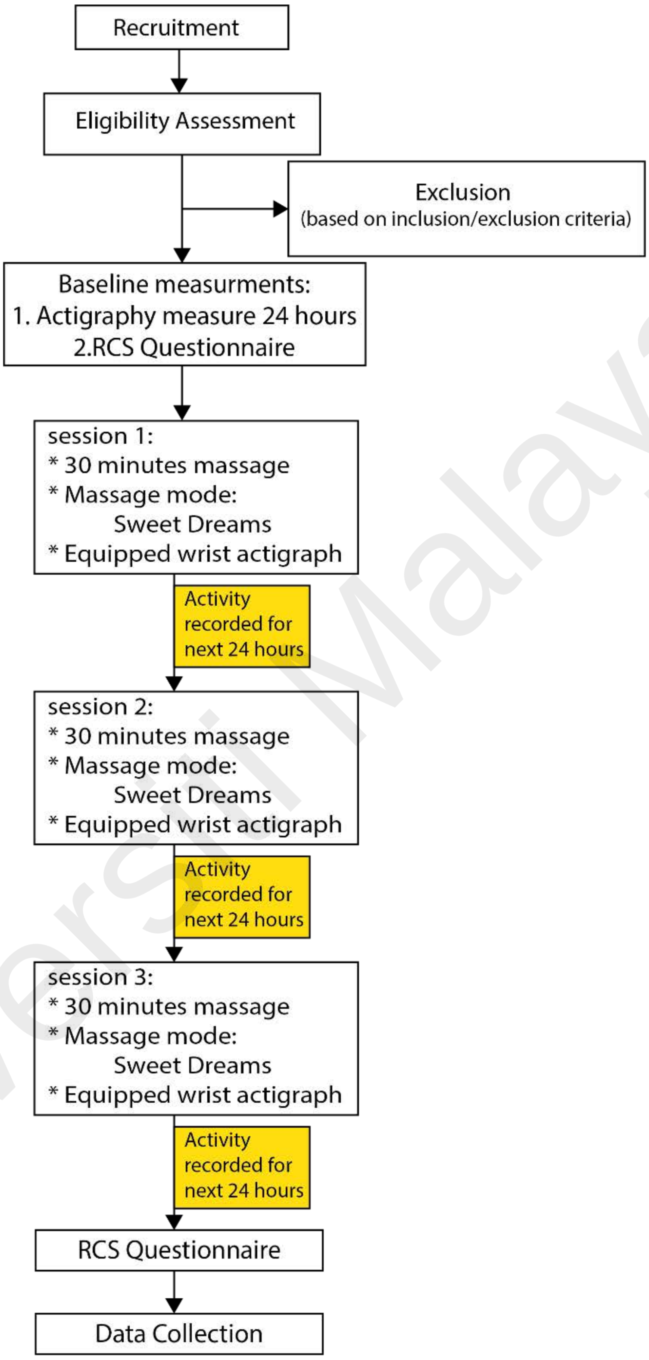



**Figure 3.4 Experimental protocol for the study investigating effect of massage on sleep metrics**

### 3.2.3 Apparatus and Outcome Measurements

#### 3.2.3.1 Massage chair configuration

For the purpose of this experimental study, a pre-programmed massage mode - "Sweet Dreams" was used. Participants were asked to remove any bracelets, watches, or sharp objects for safety reasons.

#### 3.2.3.2 Wrist Actigraphy

In this study, Actigraph GT9X Link was used to objectively assess sleep quality. The Actigraph is a small wrist-worn device that continuously monitors human activity or movement. Researchers have stated that periods of movement suggest wakefulness whereas those of relative stillness likely correspond to sleep or quiescence (Smith et al., 2018). The device had been reported to be at 91% and 85% in agreement with polysomnography (PSG) in terms of sensitivity and accuracy, respectively (Slater et al., 2015). Additionally, due to its small size and mobility of use, the Actigraph GT9X was better suited to the needs of this study. Data collected via Actigraphy device was processed and analysed with its companion software CentrePoint.

#### 3.2.3.3 Questionnaires

Participants were asked to fill out a questionnaire: Richard Campbell Sleep Questionnaire (RCSQ). The RCSQ consisted of five items with each item on the questionnaire set to a 0-100 mm visual analogue scale. The average of the values was used as the final sleep score. The results reflect the patient's perception of sleep quality. In a psychometric evaluation of the RCSQ, researchers found an internal consistency of 0.90 and demonstrated that scores on the scale have a correlation of 0.58 with the same sleep variables as measured by PSG (Shrivastava et al., 2014). A complete copy of the RCSQ is provided in Appendix B.

# CHAPTER 4: RESULTS AND DISCUSSION

## 4.1 Investigating effects of automated massage on skin tissue perfusion

### 4.1.1 Results

As indicated in table 4.1, skin tissue perfusion ($TP_{Sk}$) significantly increased for all massage mode sessions except for control session obtained through post-hoc ANOVA. Additionally, the mean $TP_{Sk}$ post-intervention of Deep Tissue mode (DTM) session was higher in comparison to Blood Circulation mode (BCM) and Sweet Dreams mode (SDM) sessions. While there was no significant difference between the pre-intervention measures of mean $TP_{Sk}$ in BCM and SDM sessions, post-intervention SDM was relatively higher to BCM. In fact, the percentage-change observed in the measured variable is depicted in table 4.2.

**Table 4.1 Tissue perfusion in pre-intervention compared to post-intervention in all sessions**

| Sessions | Pre-intervention | Post-intervention |
|---|---|---|
| Blood Circulation mode | 14.55 ± 3.37 | 17.57 ± 5.70 * |
| Deep Tissue mode | 16.23 ± 8.96 | 22.56 ± 7.68 * |
| Sweet Dreams mode | 14.29 ± 4.79 | 18.37 ± 6.87 * |
| Control | 11.23 ± 3.25 | 11.77 ± 1.12 |
| Measure variable: skin tissue perfusion<br>Unit of variable: APU<br>Variables reported as mean ± standard deviation<br>$p < 0.05$ indicates statistically significant difference compared to control (*) | | |

**Table 4.2 Percentage-change in tissue perfusion post-intervention compared to pre-intervention for all four sessions**

| | Blood Circulation mode | Deep Tissue mode | Sweet Dreams mode | Control |
|---|---|---|---|---|
| Percentage-change (%) | 20.76 ± 69.14 | 39.00 ± 14.29 | 28.55 ± 43.42 | 4.81 ± 65.54 |
| Variables reported as mean ± standard deviation | | | | |

The within-session repeatability for all massage mode session and control is provided in table 4.3. The ICC score for control mode at 0.981 shows almost an excellent repeatability between pre-intervention and post-intervention measures of mean $TP_{Sk}$. On the contrary, ICC scores for both BCM and SDM are 0.857 and 0.834, respectively, which indicate a good score. DTM exhibits the lowest ICC score indicating poor to moderate repeatability. CV scores for all sessions ranges from 1.83 % to 9.21 % in comparing pre- and post-intervention variability of mean $TP_{Sk}$ and again, DTM shows the highest level of variance post-intervention compared to other modes. The between session repeatability scores are shown in Table 4.4 for pre-intervention measures of $TP_{Sk}$. Notably, the lowest mean difference is reported between BCM & CON at 0.092 APU and the highest at 4.11 between DTM & SDM.

**Table 4.3 Within session repeatability results for skin tissue perfusion in all four session**

| Session | ICC | CV (%) | |
|---|---|---|---|
| | | Pre-intervention | Post-intervention |
| Blood Circulation mode | 0.857 | 2.31 | 4.97 |
| Deep Tissue mode | 0.712 | 3.79 | 9.21 |
| Sweet Dreams mode | 0.834 | 2.35 | 5.16 |
| Control | 0.981 | 1.83 | 2.32 |

ICC: Intraclass correlation coefficient
CV: Coefficient of variation

**Table 4.4 Repeatability results for pre-intervention measures of skin tissue perfusion between different sessions**

| Paired sessions | Difference in mean perfusion (APU) | 95% Confidence Interval | |
|---|---|---|---|
| | | lower limit | upper limit |
| BCM & CON | 0.92 | -1.19 | 3.02 |
| BCM & DTM | 2.50 | -5.31 | 10.32 |
| BCM & SDM | 3.03 | -5.92 | 11.98 |
| CON & DTM | 2.13 | -6.21 | 10.48 |
| CON & SDM | 2.80 | -5.72 | 11.32 |
| DTM & SDM | 4.11 | -7.10 | 15.33 |

BCM: Blood Circulation mode; CON: control;
DTM: Deep Tissue mode; SDM: Sweet Dreams mode

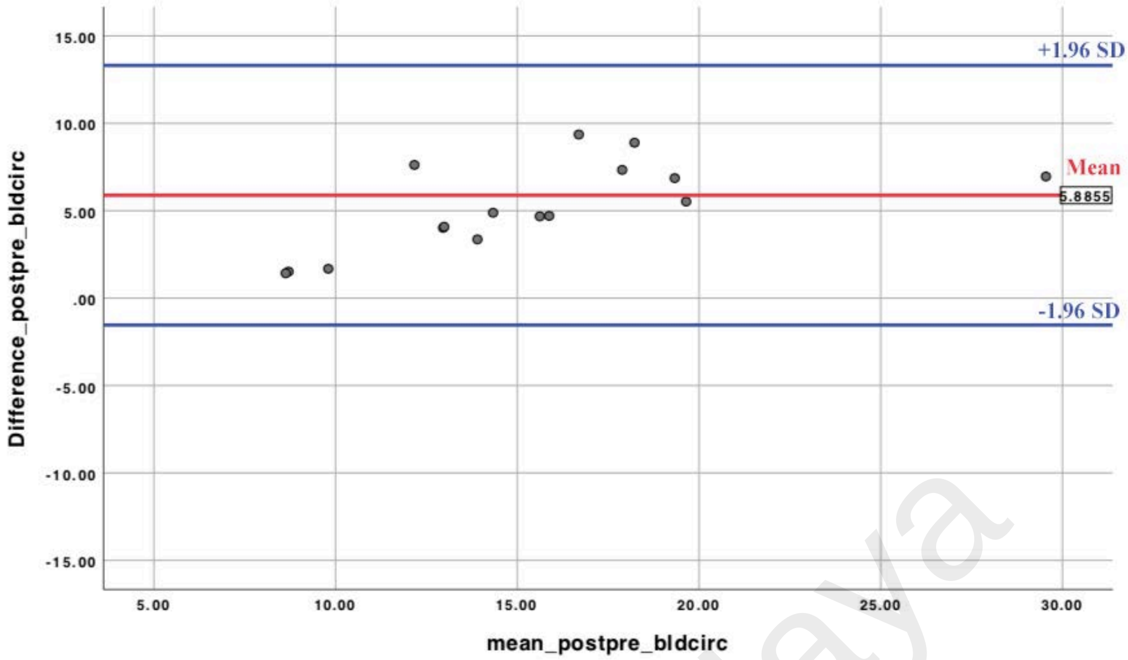


Figure 4.1 Bland Altman plot for Blood Circulation mode session

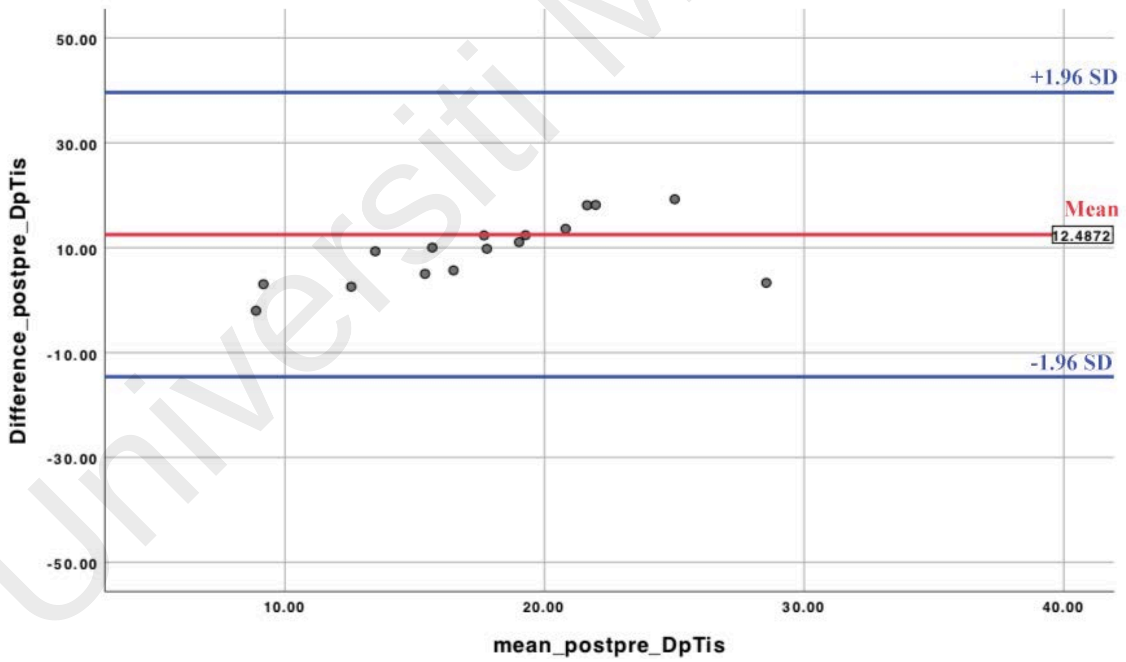


Figure 4.2 Bland Altman plot for Deep Tissue mode session

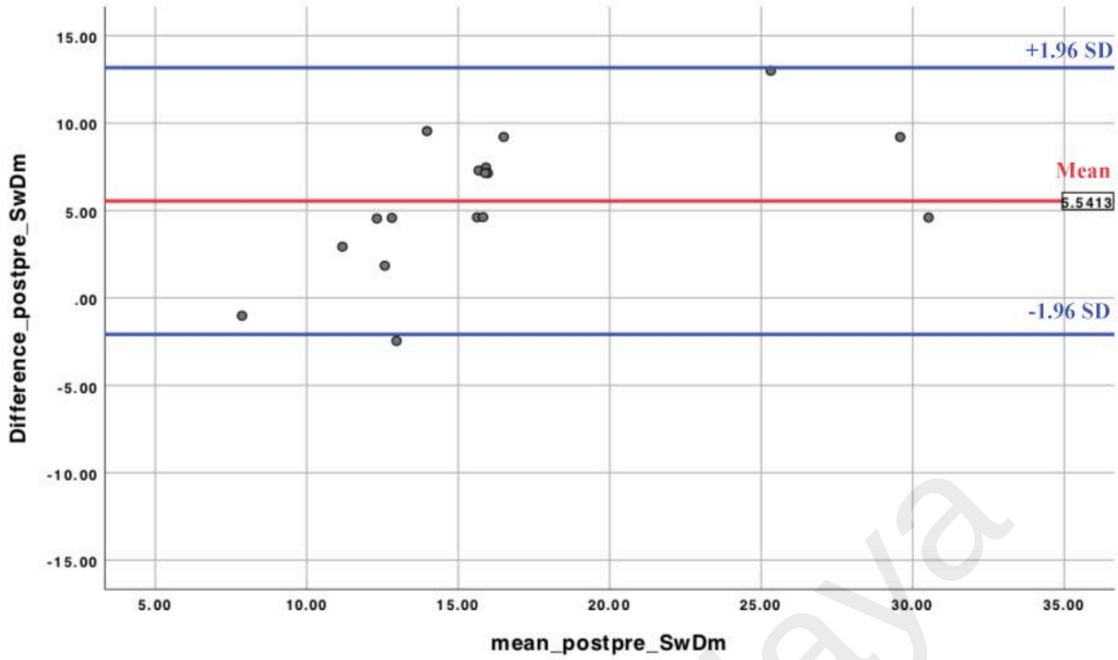



**Figure 4.3 Bland Altman plot for Sweet Dreams mode session**

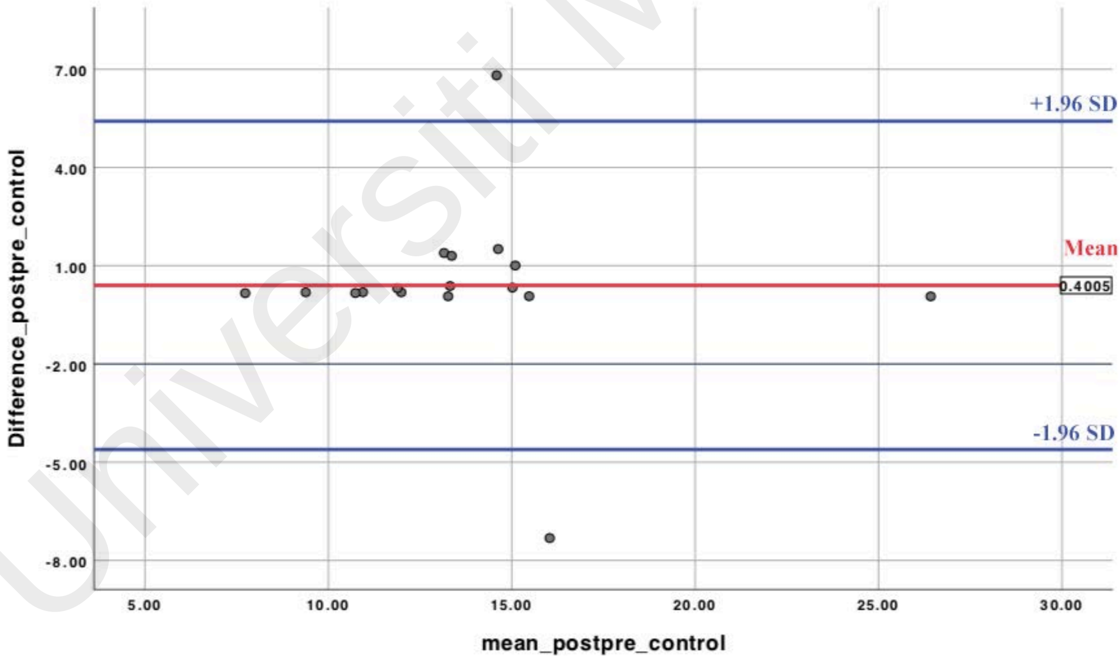



**Figure 4.4 Bland Altman plot for Blood Circulation mode session**

Figure 4.1 to 4.4 depicts the level of agreement in pre- and post-intervention mean difference against difference in mean pre-and post-intervention $TP_{Sk}$ values for each session respectively. The highest level of concordance and narrowest levels of bias is found in control session with mean difference of 0.4005 APU (95% confidence interval, limits: -4.861 to 6.345 APU). While the mean difference is almost similar in BCM and SDM sessions, the largest mean difference is in DTM with 12.487 APU (95% confidence interval, limits: -13.132 to 41.611 APU).

### 4.1.2 Discussion

In this experiment, the changes in the pre-intervention and post-intervention measures of skin tissue perfusion ($TP_{Sk}$) were assessed with a single-point optical LDF. As a reliability index for the pre- and post-intervention measure, the Intraclass Correlation Coefficient (ICC) was calculated. Generally, an ICC value above 0.75 is assumed to have workable levels of repeatability, although in clinical settings, a score above 0.9 is required to be considered acceptable (Chen et al., 2009). The repeatability scores derived from the current study shows good levels of repeatability except for DTM session where within-session repeatability is considerably lower than other sessions. This is further illustrated in the variability scores seen in CV values where post-intervention DTM was 9.27% indicating that subject variance post-intervention was considerably higher assuming that random effects from operator or device was low. The assumption is made on the basis that the same operator collected the data with the same LDF machine. To further illustrate the point, Tomás et al. (2012), in their study on optometry did report that similar devices had small variations in repeated measures of retinal perfusion for intra-observer scores for the same device. However, Kubli et al. (2000) suggest that due to only single optical fibre, the LDF probe may be limited in terms of reproducibility as compared to multipoint LDF. In addition, in this study, the placement of the probe was restricted to a very small area on the skin. According to Berardesca et al. (2002), LDF readings can be further offset because of poor subject compliance and thus, artefacts generated from movement. Arguably though, in this study, the pre-intervention and post-intervention CV scores were considerably low indicating lower level of variability in $TP_{Sk}$ in continuous measurements.

Analysing the between-session repeatability score, the differences in mean tissue perfusion between paired sessions could be generated from possible shortcoming in the spatial resolution of the LDF (Lackner et al., 2004) . In a study by Saltin et al. (1998), the authors reported that under similar condition, there were dispersion in perfusion levels measured on the same site of the skin in multiple measures and suggested that the occurrence may be due to limited resolution by optical measuring devices. In terms of automated massage effect on tissue perfusion, the current study shows that post-intervention $TP_{Sk}$ significantly changed in all sessions except for control. Mechanical stimulation induced from manually applied massage has been shown to improve tissue perfusion (Joseph et al. 2018). Charkoudian et al. (2010) had also suggested in their study that pressing and pulling action displacing the fascia of the skin causes friction which in turn may increase the temperature in the surrounding skin tissue. Physiologically, this thermoregulatory reflex actively constricts subcutaneous vessel constriction in that particular site and as a response to this change, passive vasodilation occurs in surrounding tissues and subsequently pushing blood via the occluded vessel and thereby increasing circulation. This process leaves the area treated relatively warm because of heat dissipation (Hinds et al., 2004).

In our study, the participants undergoing massage did report on sensation of warmth after massage session, however, the temperature on the site of back muscles and leg muscles was not actively measured. Again, the different massage modes used in this study (BCM, DTM and SDM) are technically different in terms of pressure application and site of application. In comparison to BCM and SDM, DTM is more concentrated in application of pressure for longer duration on the latissimus dorsi muscles and it has been reported that in treating oedema on the back muscles, patients who received moderate to high pressure massage on the latissimus dorsi muscles showed better improvement in circulation (Yeun, 2017). In fact, according to Nelson (2015), deeper and stronger massage may be responsible for stimulating the release of a neurotransmitter called histamine, which may potentially increase the rate at which sub-cutaneous vessels widen and consequently increase the rate of perfusion. The increase in tissue perfusion post-intervention in DTM session may potentially be due to relatively high-pressure massage applied during that session.

## 4.2 Investigating effects of automated massage on sleep metrics

### 4.2.1 Results

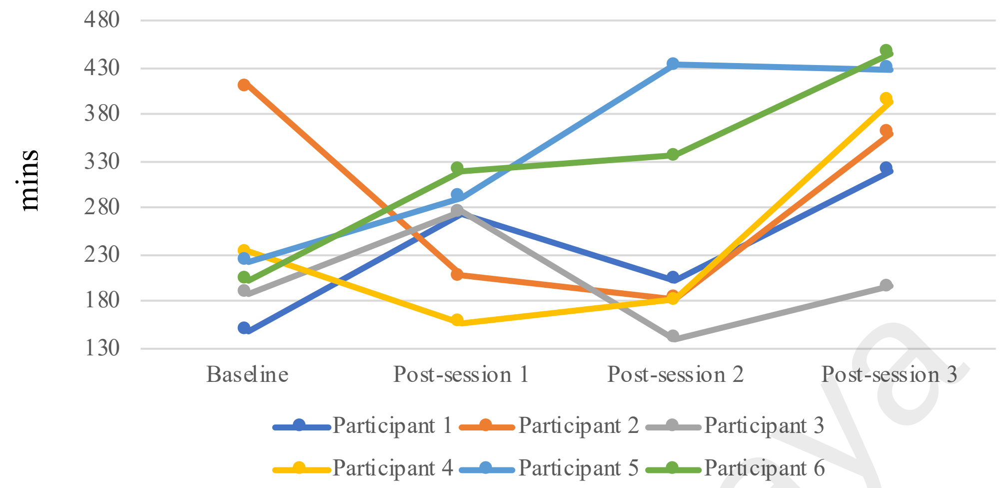



**Figure 4.5 Total sleep time (in minutes) in the three subsequent sessions compared to baseline**

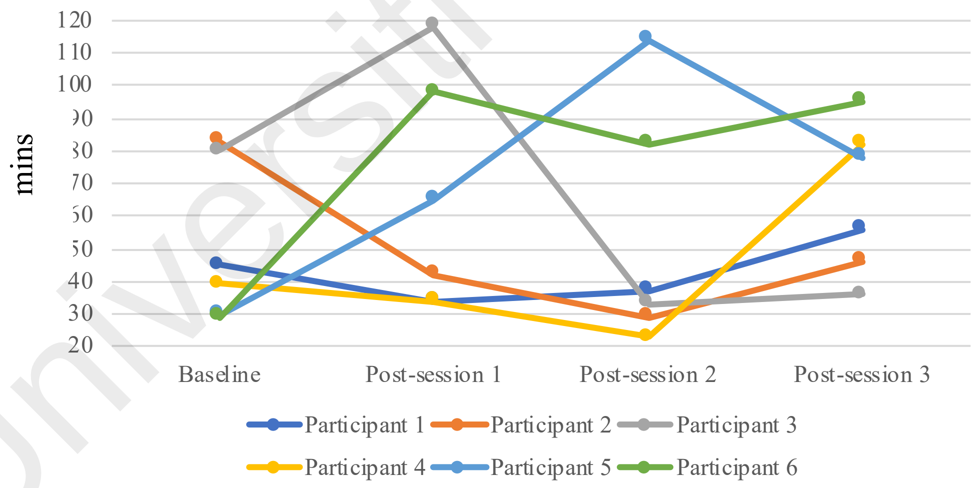



**Figure 4.6 WASO (in minutes) in the three subsequent sessions compared to baseline**

The baseline measures for total sleep time ranged from 155 – 400 minutes as shown in figure 4.5. All except the second and fourth participants exhibited reduction in sleep time following the first post-intervention session. On the night following the second session, the third participant showed a sharp decrease in total sleep time. Similarly, the total sleep time decreased by 40 minutes for the first participant whereas all other participants experienced an increase in total sleep time. Finally, on the night following the last session, all participants displayed increase in their total sleep time ranging from 190 – 440 minutes except the fifth participant, whose total sleep time decreased by 8 minutes.

The incidence of waking up after falling asleep was reported as the parameter Wake-time After Sleep Onset (WASO) represents sleep disturbance in minute time. The WASO scores are shown in figure 4.6. At baseline, the WASO scores for the second and third participant were the highest at 84 minutes and 80 minutes, respectively. Following the first post-intervention session, in addition to the third participant, the fifth and sixth participant exhibited an increase in the WASO scores, however, the other three participants recorded a decline. WASO scores for all except the fifth participant declined after second session with participant no. 3 showing the highest reduction by 85 minutes. At the end of the last session, the WASO scores for all participants ranged between 35 – 98 minutes.



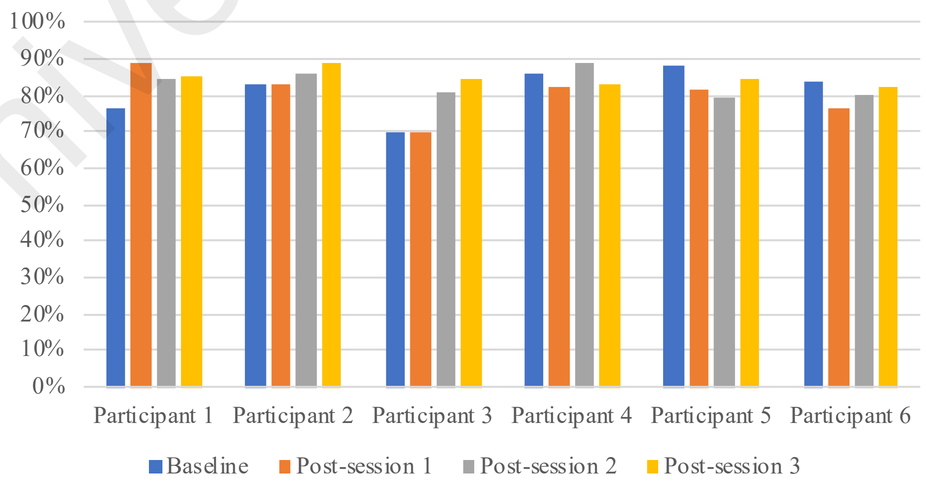



**Figure 4.7 Sleep efficiency in the three subsequent sessions compared to baseline**

Figure 4.7 shows the total sleep efficiency changes over the course of all sessions starting from the baseline measurements. The baseline sleep efficiency scores ranged from 70 – 88 %. All but the first participant experienced an increase in sleep efficiency after the first massage session. The night after the second massage sessions was marked by slight increase in sleep efficiency for all except the first and fifth participant, whose sleep efficiency only decreased marginally. The efficiency scores at the end of the last session recorded an increase in all but the fourth participant.

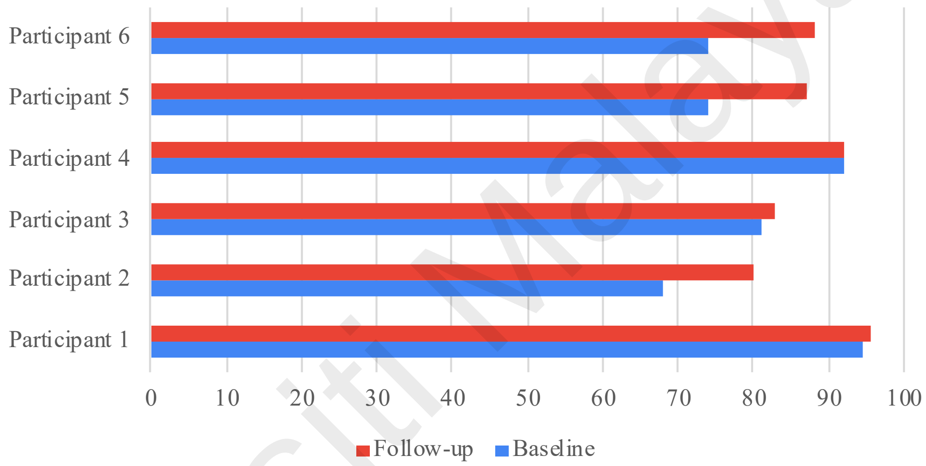



**Figure 4.8 Total sleep score at baseline and at follow-up as depicted in Richard Campbell Sleep Questionnaire**

The total sleep score calculated from the Richard Campbell Sleep Questionnaire (RCSQ) is visualised in figure 4.8. At baseline, the RCSQ sleep scores ranged from 68 to 94. At follow-up, after the end of the final session, the total score improved by more than 10 points for the second, fifth and sixth participant whereas all other participant's had marginal increase in their sleep score.

### 4.2.2 Discussion

In our study, participants were subjected to massage therapy imparted via an automated massage once every day for three consecutive days. While most participants had shown to improve their total sleep time at the end of the study period not excluding two participants whose sleep time fluctuated at greater magnitudes compared to the other four. In between the nights following first and second session of massage intervention there appears to be unusual levels of variations among the sleep times for the participants. Although none of the participants had been reported to be clinically diagnosed with sleep disorders, at baseline, all but one participant had lower than average total sleep time ranging from 2.7 – 4 hours only (figure 4.5). Following session 1 and 2, there is marginal displacement in total sleep efficiency for most individuals. Participants (#4, #5 & #6) who experienced a decline in sleep efficiency after the first session, had either decreased amount of total sleep or increased amount of wake-time after sleep (WASO) or both. In fact, WASO, which is a marker for fragmented sleep or sleep interruption, may have decreased the sleep efficiency despite more total sleep time compared to baseline. This is more evident in the case for participant no. 3, who despite having only 2.3 hours of sleep on the night after second massage intervention session, shows an increased level of sleep efficiency because their WASO had drastically reduced. Interrupted sleep is not uncommon in healthy adults and generally not more than 30 minutes in monophasic sleep (Loredo et al., 2004). Surprisingly, in our study, the WASO is unusually long for certain participants. Research in sleep studies have reported that longer and more frequent interruptions in sleep can prevent individuals from drifting into deep sleep (e.g., stage 2 of non-REM) and thereby reduce total sleep time. One possible reason for these intermittent session variations in sleep time could be that the participants under study were all university level students who are more habituated to a disruptive sleep routine caused by use of mobile devices during sleep time. In fact, a study on American college student by Dowdell & Clayton (2019) reports that groups of students who spent more late hours waking up on smart phones and using computers had more instances of fragmented sleep. Radiations generated from these devices can disrupt the natural circadian rhythm by reducing the level of melatonin secretion which is vital for a sound sleep. Nevertheless, in our study, the participants self-impression of their sleep as indicated by the difference in baseline and follow-up rating (figure 4.7) shows increased quality of sleep and this commensurable to the objective sleep quality score (figure 4.6) generated by the actigraphy device.

# CHAPTER 5: CONCLUSION

This dissertation reports on two studies, each of which examines the effects of automatically applied massage on skin tissue perfusion and sleep metrics respectively. The first study included 17 participants who underwent 30 minutes of four session including a control session, where their skin tissue perfusion was measured before and after each session with a single-point optical laser doppler flowmeter (LDF). Results indicated that compared to control session, all three massage mode sessions had significant changes in post-intervention tissue perfusion with Deep Tissue massage mode session exhibiting largest variability in tissue perfusion immediately after the session. Repeatability analysis calculated for the within-session variability of repeated measures showed moderate to good repeatability scores for mean perfusion in the same session. Furthermore, there was no significant variation between pre-intervention perfusion measures for different sessions. Post-intervention tissue perfusion in Sweet Dreams mode was marginally higher compared to Blood Circulation mode; however, mean post-intervention perfusion score for Deep Tissue massage mode significantly higher compared to both Blood Circulation and Sweet Dreams mode. This is suggestive that compared to moderate pressure massage modes, deeper and more stalwart pressure applied through Deep Tissue massage mode may potentially be more effective in augmenting tissue perfusion. In the second study, 6 male participants underwent three consecutive days of massage – single sessions per day. Participants sleep activity was monitored through an Actigraphy device and their self-impression of sleep recorded with a questionnaire. Although participants sleep scores improved at the end of the study period together with their sleep efficiency as recorded by the actigraph device, the trend in the changes observed in different sleep metrics was not continuous and uniform throughout all participants following each of the three sessions.

## 5.1 Study Limitations

There are several limitations in both studies. First, there is limitation of sample size. The small sample size in the first study cannot provide sufficient strength to the statistically significant outcomes reported. Second, in our study on massage effects of skin tissue perfusion, the measurement instrument was only limited to a single point in the body and by design had limited spatial resolution and sensitivity to movement artefacts. The optical properties of the LDF also limits the measurement to surface changes and does not illustrate on perfusion levels on deeper arteries.

In the second study, the inconsistencies generated in sleep metrics in intermediate sessions could have due to lack of reporting on actual bedtime by participants. Furthermore, because of a very small sample population a proper statistical model could not be constructed to further illustrate on the findings.

A common limitation for both studies is the total duration or period of the studies. None of the studies elucidate on the longitudinal effects of massage on tissue perfusion or sleep parameters.

## 5.2 Future Recommendations

In evaluation of automated massage on tissue perfusion, future research should first and foremost allocate larger sample size to strengthen the experimental findings. On a measurement level, instead of single point optical devices, multi-point optical modalities should be utilized to capture site-to-site variations. One possible suggestion for reducing unwanted movement artefact is to either cushion and bolster the site or region being measured. On a design level, future works should focus on long term effects of massage on peripheral circulation. In addition, the deeper vasculatures should be examined with other modalities such as doppler ultrasound.

Future studies investigating sleep parameters and how massage affects these should also opt for longer data collection in their research design. Particularly, a longer baseline data should be recorded to capture the actual sleep score of participants. Clinical evaluation of the participant's sleep score should be opted. If conducted on a clinical premise, in addition to actigraphy, nocturnal video recordings of participants sleep should be captured to better corroborate with data from actigraph.

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## LIST OF PUBLICATIONS AND PAPERS PRESENTED

**Referred Scientific Publication:**

1. Paul, A., Wee Lai, K., Usman, J., Yazed Ahmad, M., Hamidreza, M., Maryam, H., & Ong, Z. C. (2021). Investigating the Effects of Ogawa Master Drive AI Automated Massage on Blood Circulation and Sleep Quality. *Journal of Medical Imaging and Health Informatics*, *11*(5), 1357–1363. https://doi.org/10.1166/jmihi.2021.3810