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Research Article

Short Term Sensory and Cutaneous Vascular Responses to Hand Exercise

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Abstract

Study Design: Randomized Cross-over, repeated measures, pretest post-test design.

Objective: To determine the normal short term impact of two different intensities of hand exercises (high and low) on sensory and vascular functions.

Background: Hand exercise is used for a variety of clinical conditions. There is scarcity of literature on the normal effects of different intensities of hand grip exercise on sensory and vascular function.

Methods: Twenty healthy volunteers aged 18 to 50 yrs. (Mean age: 29.6 ± 8.83 yrs.) were recruited for the study. Superficial palmar blood flow (sbf) in the hands was determined using Tissue viability imager. Sensory perception thresholds (sPT) for ulnar and median nerves were determined using the Neurometer, from ring fingers to assess A beta (Aβ at 2000 Hz) and C fibre (at 5Hz) function. The trial included 3 conditions: no exercise or rest, high intensity exercise and low intensity exercise. Subject's two hands were randomly allocated to one of the two group sequences (AB or BA). Scores were obtained before and immediately after the hand exercises and rest. Differences were analyzed using general linear models (repeated measures).

Results: Neither of the exercises had a significant effect on sbf or sPT at 2000Hz and 5Hz as there were no differences over time ($p>0.05$); nor was there a condition and time interaction ($p>0.05$). Similar results were found for rest ($p>0.05$). Age and gender also had no significant effect on either measures ($p>0.05$).

Conclusion: This study found a lack of short term physiological changes in sbf and sPT of Aβ and C fibres following brief low intensity and high intensity hand grip exercise. The exercises may not have elicited cutaneous thermoregulatory responses (change in internal tissue temperature), but perhaps the non-thermoregulatory responses might have led to the observed findings.

Level of evidence: Therapy; Level 2b

Keywords:

Skin; Blood flow; Sensory perception threshold; Palm; Dynamic hand exercise

Introduction

Regular exercise is used to improve muscle function and functional ability in healthy and patient populations. Physiological responses to exercise are affected by dosage and type of exercise and so can vary with: frequency (how often exercise is performed), intensity (resistance), and duration (number of repetitions or time the exercise is performed), muscle contraction type, range of motion, speed of movement, and mode of exercise [1-4]. Control of blood flow to skeletal muscles during exercise occurs through somatic (sensory) and sympathetic neural pathways. The activation of skeletal muscle fibers by somatic nerves results in vasodilation and functional hyperaemia [5]. Sympathetic activation results in vasoconstriction and maintenance of arterial blood pressure [5]. The effects of these respective neural control systems interact throughout the vascular resistance network of skeletal muscle to facilitate coupling between the vascular supply of oxygen and the metabolic demands of the contracting muscle fibers [5].

Skin is the only readily accessible organ for which blood flow can be measured noninvasively through noncontact imaging. Due to the essential link between microcirculation function and adequate tissue oxygen delivery, the tissue blood supply has been noted as a crucial indicator of injury and disease [6]. Hence, skin is sometimes used as a model of generalized micro vascular function [7-9]. Dynamic physical exercise induces an increase in the production of heat in active muscles and increases core body temperature. Core body temperature is the main thermal input which stimulates the thermoregulatory center (the hypothalamus), which in turn induces vasodilation in the skin [10]. Skin blood flow thus plays an important role in temperature control via thermoregulation, through its responses to heat and cold stress [10]. Non-thermal factors associated with exercise such as the sympathetic stimulation, baroreflex and exercise pressor reflex also affects cutaneous circulation, [10-12] through its responses to changes in arterial and central venous pressure. The baroreceptors reflexively modulate skin blood flow, regulate central blood volume and maintain blood pressure (BP) during a BP challenge, exercise and heat stress environments [10]. Local vasoactive substances (carbon dioxide, hydrogen ions etc.) released by the active muscle during exercise are responsible for the increase in blood flow to muscle through the exercise pressor reflex which is elicited by these substances [10,13]. Control of blood flow is thus influenced by myogenic activity and local concentrations of muscle metabolites. As skin vasomotion is influenced by thermal and non-thermal factors associated with the exercise, the thermal input–output relationship in the control of cutaneous circulation during the exercise differs from that at rest [10-12]. Hence, monitoring sensory and vascular responses in skin during exercise provides an indication of changes in the neurovascular function.

Cutaneous microcirculation differs according to the location in human body and has few anatomical variations. Most of the body surface is covered with hairy or non-glabrous skin, whereas the fingers, lips, ears, forehead, palms, and plantar aspects of the feet are covered with non-hairy or glabrous skin [14]. In the hairy skin, the cutaneous microcirculation is organized as an upper and lower horizontal plexuses. These two plexus lie in an area between the dermal subcutaneous interface and papillary dermis [14]. In addition to these two plexuses, glabrous skin also contains a high proportion of arterio-venous anastomoses. Arterioles in glabrous skin are innervated solely by noradrenergic sympathetic nerves, whereas arterioles in non-glabrous skin are innervated by both noradrenergic and cholinergic sympathetic nerves [15]. The skin vascular responses to exercise have been shown to differ between glabrous regions such as the palm and sole, and non-glabrous regions such as the dorsal hand and forearm [4,16-18].

Previous literature on the effects of exercise on cutaneous vascular responses report muscle activity at one site and measurement of skin blood flow at a different site. For example, previous investigators measured skin blood flow either after a short bout of isometric hand grip exercise or after few weeks of hand grip training [19] from the volar aspects of forearm, instead of the palmar region where the muscle activity takes place. In addition, the effects of the intervention (exercise) on the tissues most directly affected by the treatment were not measured in those trials. Skin blood flow is typically obtained with laser-Doppler flowmetry (LDF) or laser-Doppler imaging using a single-point LDF (probe) either from the forearm or the finger pad [9,19]. As described earlier, there is a higher vessel density and high proportion of arteriovenous anastomoses in the palms and finger pads when compared to the forearm region. Hence, LDF responses obtained through the single point LDF is prone to variability according to the anatomy of underlying vasculature [14,19].

An index of skin blood flow can also be obtained using a novel technique called Tissue Viability Imager(TiVi), which has the capability to measure the red blood concentration (RBC) in upper dermal tissue [9,20]. The TiVi responses can be explained by physiological understanding and can be analyzed directly without any equation as in LDF (LDF flux/MAP). Unlike the LDF which uses a small single-point LDF probe (which is very small compared to the treatment area) to capture the RBC flux in a finger pad, TiVi system directly captures the RBC over the whole treatment area. Dynamic hand grip exercise involves all muscles in the palm and the images can be captured over the whole palmar aspect using TiVi which are much larger than those obtained through single point LDF probe. TiVi is not affected by the velocity or movement of blood flow in circulation as in LDF, because it only captures the amount of RBC in the area at that time point [20].

Palmar skin is also richly populated by sensory nerves, which respond to thermal, chemical, and mechanical stimuli to provide feedback to the central nervous system and influence cutaneous arteriolar tone via the release of neuropeptides and other vasoactive agents [21,22]. It is possible to perform direct measurement of the functional integrity of sensory nerve fibers using the current perception threshold (CPT) test [23]. The CPT is the minimum amount of transcutaneously applied current that an individual consistently perceives as evoking a sensation. It is a quantitative sensory test used for functional analysis of A-beta (Aβ), A-delta (Aδ) and C fibres [23]. This method is increasingly used for assessment of sensory function in clinical practice such as epidural anesthesia [24], skin graft surgery [25] and chronic lumbar radiculopathy etc [26, 27].

Currently, there is a scarcity of trials that have looked at the short term effects of low intensity and high intensity exercises on the sensory and vascular responses in the hands of healthy individuals. Hence, the purpose of this study was to see the impact of two types of hand grip exercises on the superficial palmar blood flow(sbf) and sensory perception thresholds (sPT) in an area innervated by median and ulnar nerves (C7,C8). A secondary purpose was to determine if the responses were affected by age and gender.

Methods

Participants

The number needed to detect a moderate effect size for a within subject design (ES r=0.50; two-tailed α = 0.05; 80% power) was based on Cohen's criteria. (28) Thus a sample size of 20 was considered and approved by the ethics board for this research. Healthy subjects were recruited by poster advertisement in the university campus based on the eligibility criteria given in (Table.1). Subjects were divided into two age categories: 18–34 and 35–50 yrs. (Table 2). Testing was done in the St Joseph's research lab. This study was approved by the Western University Research Ethics Board. All participants read the letter of information, had their questions answered, and signed a consent form prior to participation in this study.

INCLUSION CRITERIA	EXCLUSION CRITERIA
Age 18 to 50 yrs.	Skin infection, open wound, swelling
Male & female	Menstruation, Pregnancy
No recent injury or disease to neck, shoulder, elbow, wrist, or hand within the past year	Pacemaker/ monitoring device
All subjects were informed to refrain from any kind of exercise or drinking beverages 4 hours prior to the testing	Malignancy
	Hypertension, Cardiac failure
	Hypertension, Cardiac failure
	Neurovascular injuries
	Osteoporosis
	Dislocations
	Ligament tears or injuries,
	Heart disease, Hypertension, cardiac failure.
	Deficits in sensation in the area to be treated (sensory test to identify sharp and dull sensation)
	Deficit in circulation (Digital patency test for fingers)
	Inability to understand instructions.

Table 1: Inclusion and Exclusion Criteria

Age in yrs. (mean± SD)	29.6 ± 8.83
Gender :	
Female's n (%)	13 (65%)
Male's n (%)	7 (35%)
Dominance:	
Right n (%)	18 (90%)
Left n (%)	2 (10%)

Table 2: Participant Demographics

Outcome Measures

TiVi (Tissue Viability Imager) 600 polarization spectroscopy camera (version 7.4 Wheels Bridge AB, Linköping, Sweden)

The TiVi is a reliable [29], valid [20,30] and sensitive [31] device used for a high-resolution instantaneous imaging of RBC concentration in human dermis (to a depth of 400-500 micrometers) [20]. This digital camera (Canon Rebel EOS model 450D, Japan) has shown many uses in drug development, burn investigations, pressure studies, and general research maneuvers due to the ease of use, portability, and low cost [9,20].

Participants were required to keep their shoulder in neutral, elbow in 90o flexion; forearm (s) supinated and placed approximately at the level of the heart. An outline was drawn to standardize hand position. The camera was positioned at a distance of 30 cm from the participant's hand. For each participant one image at baseline (pretest) and immediately after (post-test) exercise or rest were captured. In total 4 images per hand were used and the 'Regions of interest' were selected over the palms up to the wrist crease. Later these cropped images were used for statistical analysis.

Neurometer ® CPT/C device (Neurotron Inc., Baltimore, USA)

The Neurometer evaluates sensory nerve conduction from the periphery to the brain and has been shown to detect, screen and diagnose the abnormalities of peripheral nervous system. [32, 33] It has been shown to be a reliable and valid measure in the evaluation of mechanical neck disorders [34], and found to be specific and sensitive in the examination of carpal tunnel syndrome [34,35]. A frequency of 2000 Hz is used to stimulate the large myelinated A_β fibres (touch, pressure); a 250Hz to stimulate myelinated A_δ fibres (mechanoreceptive, fast pain, pressure, temperature), while a frequency of 5 Hz is used to stimulate the small unmyelinated C-polymodal nociceptive fibres (slow pain, temperature, post ganglionic sympathetic fibres) [32,33].

Ranged CPT (R-CPT) is a rapid sPT test in the Neurometer which is typically used to confirm or rule out sensory involvement in large samples such as screening [33,36]. In R-CPT, each frequency is repeated several times to ensure accuracy and reproducibility [33]. The Neurometer also reports values (R-CPT levels) as, the normal range (6–13), hyperesthesia (1–5), or hypoesthesia (14–25) [33,36]. R-CPT was tested at two frequencies in this study (2000Hz and 5Hz) to target two different nerve fibre types. To begin 2000 Hz stimulation, the skin was cleaned with a skin paste and then the 1 cm gold electrodes coated with small amount of gel were attached to the ring finger with an adhesive tape. Then the participants were asked to press and hold the red "Test cycle" button on the remote control box and release it as soon as they begin to feel the tingling or buzzing sensation. The machine records the response when the button is released and the same process is repeated 7-10 times until a score is displayed. In total three consecutive scores were obtained at 2000Hz. The same procedure was repeated at 5Hz. These test cycles end automatically after few repetitions (7-10 times) and the Neurometer displays score for 5Hz [33,36].

Study protocol

We used a randomized cross over (AB/BA), repeated measures design in this study. There were three conditions; a control condition (rest or no exercise), low intensity hand

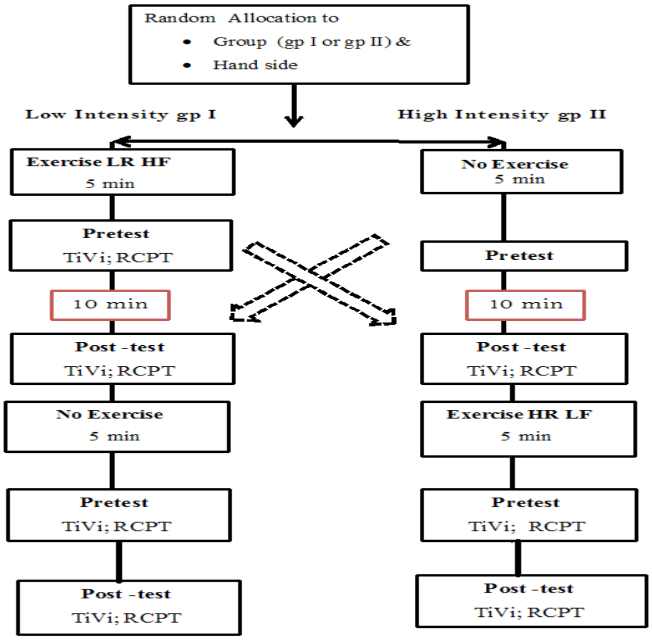


Figure 1: Flow chart for the study design (Cross-over AB/BA)

Figure legends: Rt.= right hand; Lt.= left hand; gp= group; gp I = undergoes Low intensity group sequence; gp II=undergoes High intensity group sequence; LR HF= low resistance ,high frequency; HR LR= High resistance, low frequency; 10 min washo=ut period; TiVi= tissue viability imager; R-CPT= Range current perception threshold test at 2000 Hz & at 5 Hz; ---- = dashed arrow represents the cross over to other group sequence and hand side.

Participants were assigned by concealed random allocation; using two sealed envelopes, to one of the 2 group sequences (low intensity group or high intensity group) and one of the two hands (right or left). A 10 min washout period was used to minimize any potential carry over effects of exercise. Each hand acted as its own control. The two group sequences were completed on the two hands one after the other on same day according to the protocol shown in (Figure.1). Outcome assessments and testing were all provided by a single physiotherapist.

Exercise intervention

The study protocol and rate of perceived exertion (Borg's 10 point RPE scale) were explained to each participant during the acclimatization (10 min) to room temperature. Participants were first measured on TiVi over the palmar region to assess sbf and then the R-CPT test was recorded from the tips of ring finger to assess sPT at 2000Hz and 5Hz. These two measurements were done before (pre-test) and immediately (post-test) after each control/rest condition and hand exercise in a similarme order. After completing baseline assessments, participants were either asked to rest for 5 min during the no exercise period, or perform a low intensity or a high intensity hand grip exercise based on the group sequence selected. Participants were asked to perform a warm up of hand muscles prior to the initiation of exercise. a) Low intensity (or low resistance and high frequency) exercise consisted of squeezing a low resistance Dyna gel therapy ball (pink colored, soft, 150 hardness) for a total of 5 min. One set of hand exercise consisted 25 repetitions (1 sec contract & 1 sec relax; each set was paced at <30 sec) (37) and each set was separated by a 30 sec rest interval (25 reps- 30 sec rest-25 reps-30 sec rest). b) High intensity (high resistance and low frequency) exercise consisted of squeezing a high resistance thera ball (black colored, firm, 350 hardness) for a total of 5 min. One set of hand exercise consisted 12 repetitions (1sec contract & 2 sec relax; each set was paced at > 30 sec or 36 sec) (37) and each set was separated by a 30 sec rest period (12 reps-30sec rest-12 reps-30sec rest) [adapted from ACSM]. (38) The speed and time of contraction were paced with a stop watch and metronome. RPE scale was used to monitor the level of exertion or fatigue after the exercise.

TiVi software was used to calculate the mean blood flow (A.U.) in the palms up-to the wrist crease and then the data was transferred to an Excel. The R-CPT scores obtained at 2000Hz and 5Hz (m. A.) were recorded directly from the digital display of the Neurometer CPT/C device.

Data analysis

The sbf and sPT at 2000Hz and 5Hz were assessed for differences using General Linear Models (GLM), repeated measures (SPSS version 20, IBM Inc.). Models assessed whether there were differences between baseline and immediately after exercise therapy (low intensity and high intensity) or rest. Interactions were examined for significance between time and treatment conditions. Post hoc analyses were performed using Bonferroni correction wherever necessary. Pair wise comparisons were used to perform within-group comparisons for treatment and control. The GLM model was run without covariates and then repeated with age and gender as a covariate to test for differential responses. Significance level was set at $p<0.05$ level unless otherwise noted.

Results

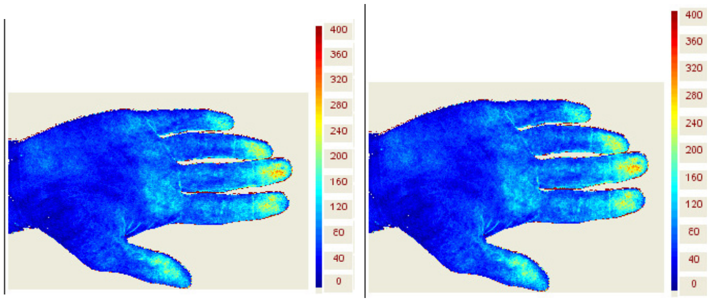
Twenty healthy volunteers who satisfied all eligibility criteria were recruited between November 2012 to February 2013 (Table.1). No data points were missing. The group means, standard deviation, 95% confidence intervals, change scores and effect size for sbf and sPT at 2000Hz and 5Hz are shown in the (Table.3) and are summarized by outcome measure below. Neither of these exercise intensities (low and high) had a significant effect on sbf or sPT at 2000Hz and 5 Hz as there were no differences over time ($p>0.05$); nor was an exercise condition and time interaction ($p>0.05$). Similar results were found for control/rest condition ($p>0.05$) (Table 3, Figure 2 (i) & (ii)). The effect sizes were small (ES $r = <0.2$) for both outcome measures before and after the exercise and rest. GLM with age and gender as covariates reveals no significant effect of age (across the two categories; 18–34, 35 -50 age groups) as well as the gender on the sbf or

	Low intensity group	**High intensity group**
	LR HF(n=20 hands)	HR LF (n=20 hands)
Skin blood flow		

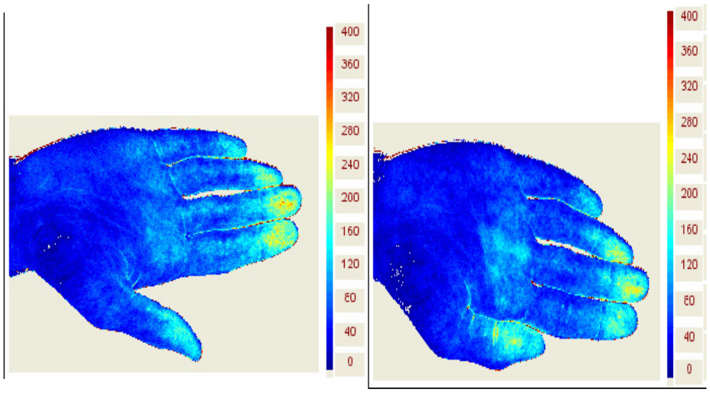
(0-400 A.U)		
Pre-test	88.7(84 - 93.3)	89.4(85- 93.6)
Post –test	91.1(86.6- 95.6)	90.9(85.7- 96.1)
Change score	2.5	-1.4
Effect size	-2.6	-0.07
R-CPT		
at 2000Hz		
(0-24 m.A)		
Pre-test	8.6(7.6- 9.5)	9.1 (8.3 -9.7)
Post -test	9.1(7.2-10.9)	9.6(8.4-10.6)
Change score	-0.5	-0.1
Effect size	-0.08	0.11
R-CPT at 5Hz		
(0-24 m.A)		
Pre-test	13.1(11.3-14.8)	14.1(12.3- 15.7)
Post-test	13.1(10.8- 15.2)	13.5(11.9- 14.9)
Change score	-0.3	1
Effect size	0.05	0.09
	Low intensity group	High intensity group
	Rest (n=20 hands)	Rest (n=20 hands)
Skin blood flow		
(0-400 A.U)		
Pre-test	88.7(84- 93.3)	89.3(85 -93.6)
Post-test	88 (84.4-9.0)	90.3(85.- 94.8)
Change score	0	-0.8
Effect size	0	-0.05
R-CPT		
at 2000Hz		
(0-24 m.A)		
Pre-test	8.5(7.5- 9.4)	9.5(8.4- 10.4)
Post-test	9.3(7.4- 11.2)	9.4(8.4 -10.4)
Change score	-0.8	0.3
Effect size	-0.1	-0.02
R-CPT at 5Hz		
(0-24 m.A)		
Pre-test	13.1(11.3-14.8)	14.5 (12.3-15.7)
Post-test	13.5(11.6- 15.3)	13.5(12.0 -14.9)
Change score	-0.4	0.1
Effect size	-0.05	0.07

Table 3: Outcome Data For Skin Blood Flow, Sensory Perception Threshold*

Figures 2 (i) and (ii)



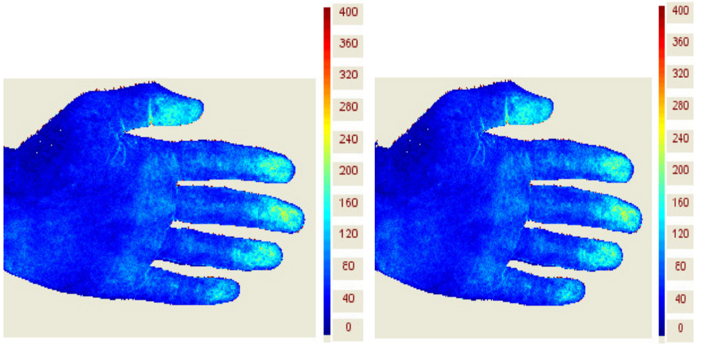
Before rest-H Before HRLF exercise



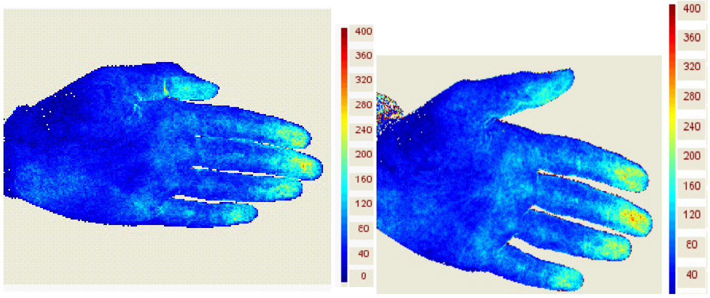
After rest-H After HRLF exercise

Figure 2: i) Responses shown on TiVi camera over the palmar region in High Intensity group; rest-H= Rest condition in High Intensity group; HRLF exercise = High Resistance and Low Frequency exercise.

*Basal skin blood flow appears blue and if it increases the color changes to green, yellow and red as shown in the scale (0-400A.U)



Before rest-L Before LRHF exercise



After rest-L After LRHF exercise

Figure 2: ii) Responses shown on TiVi camera over the palmar region in Low Intensity group; rest-L= Rest condition in Low Intensity group; LRHF exercise = Low Resistance and High Frequency exercise.

*Basal skin blood flow appears blue and if it increases the color changes to green, yellow and red as shown in the scale (0-400A.U)

Discussion

This study found a lack of short term physiological changes in superficial palmar cutaneous blood flow and sensory perception thresholds following a brief low intensity or high intensity hand grip exercise. The responses were also not affected by age or gender. We could not find any similar study in the literature which reported neural and vascular responses in the palm (glabrous skin) after high intensity and low intensity hand grip exercises. The closest findings related to our study which measured vascular and neural responses after resistant hand exercise was by Akira et al [39]. These authors looked at the effects of vibration and noise on sympathetic nerve activity in fingers and palm (glabrous skin) of five healthy volunteers. One of the three experiments in their study was to observe the effect of isometric handgrip exercise (a constant gripping force of 2 kg) on skin blood flow, skin temperature and median nerve sympathetic activity in the hands before and after 5 min. No significant changes were observed in the sympathetic nerve activity or skin blood flow during and after isometric handgrip exercise when compared to the values at rest [39].

Our results were consistent with the reports by Akira et al., [39] with respect to skin blood flow and sensory nerve function (C fibres are post- sympathetic ganglionic). But direct comparison was not possible because the current study looked at sbf and sPT from the ring finger noninvasively (median and ulnar innervation zone) before and after two types of dynamic exercises, while Akira et al., assessed sympathetic neural activity at elbow level directly by inserting needle into the median nerve and measured skin blood flow from the tips of middle finger using laser Doppler flowmetry, before and after a constant isometric hand exercise.

Another study by Bartholomew et al., [40] investigated the effects of 20 min of self-selected resistance exercise (circuit weight training, stationary cycling) on pressure pain thresholds and pain tolerance in healthy volunteers. These authors found that pressure pain thresholds remained unchanged following exercise and control conditions, but pain tolerance increased across time [5]. In the present study Aβ perceptions did not change after control and after the two hand exercises. Because Aβ function is to detect and transmit touch and pressure, the sPT at 2000Hz can be presumed to have responded similar to pressure pain thresholds in Bartholomew's experiment [40]. However there was pain component along with pressure component in the pressure pain threshold test. Hence, direct comparisons were not possible due to differences in site (legs), methods (exercise protocol was cycling) and assessments used in these studies.

Differing methods of sbf measurements and treatment protocols do not allow for direct comparisons to be made between the research studies that have been published to date. The observed changes in sbf and sPT before and after exercise and rest may be explained by the body's physiological responses. Skin blood flow in the palm has been reported to be regulated by 3 mechanisms: 1)Thermoregulatory reflex control [11], 2) Non-thermoregulatory reflex control [10,41], and 3) Auto regulation [42]. Thermoregulatory reflexes, which include skin blood flow responses to heat and cold stresses, exert their effects on the skin circulation through two branches of the sympathetic nervous system: a noradrenergic vasoconstrictor branch and an active vasodilator branch [11]. Nonthermoregulatory reflexes, which include skin blood flow responses to changes in arterial and central venous pressure and exercise stresses, also operate through the two aforementioned branches of the sympathetic nervous system; however, the glabrous/palmar skin operates only through the vasoconstrictor branch [10,11,41]. In the auto-regulation process, throughout a specific range of arterial blood pressure, steady-state blood flow is maintained at a fairly constant level [44]. Previous reports on cutaneous circulation has shown that, independent of neural control of blood flow, glabrous/palmar skin has the ability to buffer blood pressure oscillations and demonstrates a degree of dynamic auto-regulation. Conversely, nonglabrous or hairy skin has a diminished dynamic auto regulatory capacity [42].

We first tried to relate observations in the present study to some of the physiological findings reported earlier on the cutaneous responses to exercise on non-glabrous or hairy skin in terms of thermoregulatory control [11,12,43,45,46]. These authors [11,12,43,45,46] showed that the onset of acute dynamic exercise involves a transient reduction in skin blood flow mediated by increased cutaneous sympathetic (vasoconstrictor) outflow . As dynamic exercise progresses, core temperature (internal body temperature) begins to rise while skin blood flow remains unchanged until a temperature threshold (Tc) is reached (Tc< 37◦C). Once this threshold is crossed in internal body temperature (Tc ≥38 ◦C) [11,12,43,45,46], or exceeds a specific level in the deep tissue temperature of a local exercising muscle ,(47,48,49) the skin blood flow begins to rise linearly with increasing temperature [47,50,51]. This post-exercise elevation in core body temperature is intensity dependent, hence higher post-exercise temperatures were found to be associated with higher exercise intensities [2]. Also the thermal afferents from an exercising tissue (muscle, vein or bone around the muscle etc) might directly affect thermoregulatory responses [47-49]. Hence, it is possible that the hand exercises used in this study did not cause a persistent post exercise thermal load that was substantial enough to stimulate an increase in core temperature [2,52]. In the present study we monitored rate of perceived exertion (RPE) during and after the exercise to note level of fatigue or exertion (if any). All the participants described their rate of perceived exertion to be 'weak' or very weak'. From this we can presume that both low intensity and high intensity exercise protocols were not so intense to rise the local muscle tissue temperature [47-49], thus causing no variation in sbf. There was no variation in sbf and sPT after control as well. We presume that this response might have been due to the resting condition of the participants during 'no exercise period' in a thermo-neutral environment.

Secondly, it is also possible that the sbf and sPT did not change after exercise due to the non -thermo regulatory control of skin blood flow (from muscle's exercise pressor reflex or baroreflex etc.). It has been reported that control of blood flow in the cutaneous microcirculation depends primarily on cutaneous arteriolar tone, which is influenced by many factors including sympathetic stimulation, myogenic activity, and local concentrations of specific metabolites in muscle (e.g., carbon dioxide, hydrogen ions) [22]. In addition to this, skin is also richly populated by sensory nerves, which responds to thermal, chemical, and mechanical stimuli to provide feedback to the central nervous system and influence cutaneous arteriolar tone. Aβ fibres play a key role in providing tactile sensory inputs from palmar skin to the brain. Hence, intact touch and pressure sensations are important to initiate voluntary contraction as well as maintain the muscle work according to the different force loads generated during hand grip exercise [53]. So there is a possibility that the observations in the present study could have been due to the mechanical stimuli from rhythmic finger squeezing Blood flow to active skeletal muscle is required to meet metabolic demands. Blood flow redistribution from other regional circulations contributes to the enhanced muscle blood flow [10,12]. It has been previously reported that after exercise, oxygen consumption (VO2 max) and energy expenditure in the muscle remain above resting values for a period of time, denoting high energy expenditure during this period [54]. The extra oxygen consumption is known as excess post-exercise oxygen consumption (EPOC). Evidence from past reports suggests an exponential relationship between exercise intensity and the magnitude of the EPOC for specific exercise durations [54]. Furthermore, work at exercise intensities 50–60% VO2 max stimulate a linear increase in EPOC as exercise duration increases [55]. During recovery from relatively high-intensity exercise, it may take approximately 60 min or more for VO2 and the anaerobic metabolic rate to return to values recorded before exercise [37,55]. There is a possibility that the hand exercises used in this study might have increased the oxygen demand in the muscle tissue for a brief period after the exercises. Thus, causing blood flow redistribution from the skin to the active skeletal muscles [56], to suffice the post exercise oxygen consumption [55], which is thought to remain above resting levels for a period of time [54], before returning to their pre-exercise state.

Hence, we summarize all possible physiological mechanisms that might have led to the observed findings in this study as follows: The responses observed in palmar sbf and sPT are more likely to be linked to the non -thermo regulatory control of skin blood flow (from muscle activity, exercise pressor reflex, post exercise oxygen consumption). We exclude the influence of a thermoregulatory control and the baroreflex control from our findings. A dynamic exercise in which a significant percentage of muscle mass is engaged (~50%) generates thermoregulatory demands that are met in part by increases in skin blood flow [10,57]. The exercise protocols used in this study involved small muscles of the hand which contributes to <50% of the total body muscle mass [57]. The localized rhythmic hand exercises might not have increased body core temperatures beyond a set threshold (≥380C) to engage the thermoregulatory reflex. Further, it is unlikely that the exercises altered cardiac output, mean arterial pressure or heart rate to stimulate the baroreflex responses in the big arteries [10,58].

The underlying mechanisms demonstrated in sbf and sPT obtained with exercise however appear to be complex and multifaceted [59]. Apart from these three control mechanisms, personal factors and environmental factors have also been reported to alter skin responses. The distribution of glabrous skin is limited to the hands, feet, and faces, and is exquisitely sensitive to environmental temperature and emotional inputs. Even though the study was conducted in thermo-neutral environment in same subjects on same day to control the diurnal variations, we cannot address the issue of whether emotional inputs had any contribution to the observed findings [52,60]. It has also been reported previously that glabrous skin has the capability of both static and dynamic auto-regulation [42]. Hence, we can only presume that cutaneous auto-regulation might have contributed in some way to the observed findings.

The vasoconstrictor system in the palmar skin is the primary means of blood flow control through which exercise can exert any modifying effects [50,61]. The competition between thermoregulatory control of body temperature and the metabolic demands of exercise is also a competition between skin and the active skeletal muscle for the available cardiac output [62]. There is no compromise or reduction in blood flow to the active muscles or to the blood pressure even in heat stress [56], but there is a limit to skin blood flow through redistribution or shunting of blood towards the active tissues [62] in such conditions. The limitation to skin blood flow also varies with the level and mode of exercise used [63].

Exercise had no effect on R-CPT scores at 2000 Hz or at 5 Hz. The lack of change in sPT of C fibres (that carry sympathetic signals) is consistent with a lack of change in sbf after the hand exercise, since the palmar skin is supplied only by sympathetic vasoconstrictor nerves. This is because of the anatomical variation in the palmar skin, which gets innervation from the sensory and sympathetic vasoconstrictor nerves, contrary to the hairy skin which also gets innervated by the sympathetic vasodilator nerves [14]. Hence, any vasoconstriction or vasodilation in the palmar skin after the exercise could have been attributed to either the stimulation or inhibition of sympathetic vasoconstrictor nerve fibres. All these inferences lead us to a conclusion that the short term hand exercises used in this study were not sufficient to cause significant amount of variations in sbf and sPT as compared to the values at rest. The findings of this study indicate that local hand exercise of either high or low intensity level (using thera-balls of two different resistances) shows minimal systemic impact in individuals without injury or cardiac disease suggesting either is safe. These should be investigated in patient population as they may indicate abnormal vascular, sensory, sympathetic or muscular function.

Limitations and research recommendations

There are a number of limitations in the current study that may have affected the study findings and generalizability. Only one therapist pro¬vided the intervention and assessments. However minimal bias was expected with respect to outcome evaluation, because sPT was determined by the participants while the sbf was not controlled by either the subject or the therapist.

The TiVi system while accurate is only able to measure superficial sbf and was not a direct measure of blood flow to the deeper tissues. The sPT was recorded only from the ring finger in order to follow the recommendations of the manufacturer. Furthermore, since the ring is innervated by both median and ulnar nerves, differential effects in these nerves were not directly explored.

The participants performed exercises using 2 pre-set hand grip resistances and so there was no customization of resistance to the individual's strength. This meant that the exercise dosage varied across individuals and may not have reached a high intensity for some. However, since this approach is commonly used in clinical practice, it was selected for its clinical relevance. Due to the small size of thera-balls a couple of participants used only four fingers for exercise leading to variable exercise performance. However, this is considered a minor variation which was not under the therapist or participant control.

Future exercise study is needed to explore the effects in patients with hand injuries and with comorbid health problems. Athletes and active individuals who participate in regular physical exercise may have different skin vascular responses and this needs further research. It is possible that long term hand exercise causes physiologic changes in the vascularity or nerve function, and thus longer term effects of exercise programs should be explored. Finally, this exercise construct is only one form of exercise used in hand rehabilitation and other forms should also be investigated.

Conclusion

In conclusion, this study demonstrated a lack of short term effects on sbf and sPT at 2000Hz (Aβ) and 5Hz (C fibres) with two brief hand grip exercises. This is a non-invasive study and we deduced all relationships from the previous physiological findings. Even though the exact mechanisms behind these observations are unknown, there is a possibility that non-thermoregulatory reflexes and cutaneous auto-regulation in the palms might have led to the observed findings, and not the thermo-regulatory reflex control mechanisms. Future studies should focus on assessing therapeutic effects of different modes of hand exercises commonly used in the clinical settings and apply the same in patient population.

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