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Effect of sensory stimulation (acupuncture) on sympathetic and parasympathetic activities in healthy subjects

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Abstract

It has been postulated that sensory stimulation (acupuncture) affects the cardiovascular system via the autonomic nervous system. Previously, skin temperature, thermography, plethysmography and blood pressure changes have been used in evaluation of sympathetic nerve activity following acupuncture. By using power spectral analysis, the low frequency and high frequency components of heart rate variability can be calculated reflecting the sympathetic and parasympathetic activity. The purpose of this study was to investigate to what extent acupuncture applied into the thenar muscle and into the cavum concha of the ear induced changes in the sympathetic and/or parasympathetic nervous system in healthy subjects. *Materials and Methods.* Twelve healthy volunteers, six men and six women, mean age 34.4 (range 23–48) participated in three balanced, randomly distributed sessions. At an individual initial visit the 12 volunteers were introduced to the needle sensation by having a needle inserted into the point LI 11. The needle sensation was evoked and the subject was trained to identify the characteristic needle sensation. The introduction was followed by three test sessions. *Session A.* A short acupuncture needle, (Seirin no 3, ∅0.20×15 mm) was inserted perpendicular into the earpoint, Lu 1, in the left inferior hemi-conchae. *Session B.* An acupuncture needle (Hwato, ∅0.30×30 mm) was inserted perpendicular into the Hegu point (LI 4) in the middle of the right dorsal thenar muscle. *Session C.* An acupuncture needle (Hwato, ∅0.30×30 mm) was inserted perpendicular superficially into the skin overlying the Hegu point on the left hand. *Results.* Stimulation of the ear induced a significant increase in the parasympathetic activity during the stimulation period of 25 min ($P<0.05$) and during the post-stimulation period of 60 min ($P<0.05$). No significant changes were observed in either the sympathetic activity, blood pressure or heart rate. Stimulation of the thenar muscle resulted in a significant increase in the sympathetic and the parasympathetic activity during the stimulation period ($P<0.01$) and during the post-stimulation period ($P<0.01$ and $P<0.001$, respectively). A significant decrease in the heart rate frequency ($P<0.05$) at the end of the post-stimulation period was also demonstrated. The superficial needle insertion into the skin overlaying the right thenar muscle caused a pronounced balanced increase in both the sympathetic and parasympathetic activity during the post stimulation period of 60 min ($P<0.01$) while no changes were observed during the stimulation period. *Conclusion.* It is indicated that sensory stimulation (acupunctura) in healthy persons is associated with changed activity in the sympathetic and parasympathetic nervous system depending on site of stimulation and period of observation.

Keywords: Acupuncture; Autonomic nervous system; Heart rate variability (HRV); Sensory stimulation; Power spectral analyses (PSA)

1. Introduction

Experimental and clinical studies suggest that afferent input in somatic nerve fibres has a significant effect on pain as well as autonomic functions and hormones (Andersson and Lundeberg, 1995).

In a thermography study on 19 healthy subjects, both manual and electrical acupuncture applied unilaterally in the Hoku point in the thenar muscle produced a symmetrical long lasting warming effect indicating a reduced sympathetic activity. As the observed changes were symmetric, the authors suggest a central spinal or supraspinal mediated sympathetic effect rather than a peripheral effect. In addition, a short-term cooling effect induced by electrical acupuncture indicated a transient segmental increase in sympathetic activity (Ernst and Lee, 1985; Ernst and Lee, 1986; Sugiyama et al., 1996). Furthermore,

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the modulatory effect of acupuncture on the cardiovascular and the sympathetic system has been referred to somatoautonomic reflexes (Budgell and Sato, 1996) and found to be dependent on the functional status of the organism to promote homeostasis (Wu, 1990).

While several studies have investigated the effect of acupuncture on the sympathetic activity, only a few have explored its effect on the parasympathetic activity. Needle insertions in the vagal innervated area of the ear has been shown to reduce withdrawal symptoms and the underlying physiological mechanisms have been described as increased parasympathetic activity (Severson et al. 1977; Mendelson, 1978).

The neural regulation of circulatory function is mainly effected through the interplay of the sympathetic and vagal outflows and in most physiological conditions the activation of either outflow is accompanied by the inhibition of the other. The sympatovagal balance is tonically and phasically modulated by the interaction of at least three major factors: central neural integration, peripheral inhibitory reflex mechanisms (with negative feedback characteristics) and peripheral excitatory reflex mechanisms (with positive feedback characteristics) (Malliani et al., 1991). This interaction takes place at both spinal and supraspinal levels with afferent input exciting pre-ganglionics on the same or adjacent segments resulting in somatosympathetic and/or somato-parasympathetic reflexes (Sato et al., 1997).

Furthermore, thermography (Thomas et al., 1992), plethysmography (Cao et al., 1983) microneurography (Knardahl et al., 1998), blood pressure measurements (Ohsawa et al., 1995; Dyrehag et al., 1997), and skin temperature (Dyrehag et al., 1997) have all been used in evaluation of sympathetic nerve activity following acupuncture. These methods measure the net outcome of the changes in the autonomic nervous system (ANS) on specific target organs. By using power spectrum analysis (PSA) fluctuations in the high frequency (HF) component of heart rate variability (HRV) visualize the component of parasympathetic activity on HRV (Malliani et al., 1991; van Ravenswaaij-Arts et al., 1993), and low frequency (LF) component of HRV may be considered as a marker of sympathetic activity on HRV. However, some disagreement exist on the LF component (Task Force on the European Society of Cardiology, 1996). Several approaches on analyzing HRV exist and Fast Fourier Transformation (FFT) is commonly used (Malliani et al., 1991).

One of the most studied acupuncture points is the Hoku point (L14) in the thenar muscle that is innervated by sensory and autonomic, mainly sympathetic, fibres (Suter and Kistler, 1994). The concha of the ear represents an area, which is innervated by sensory and mainly parasympathetic fibres with multiple connections to the central nervous system (Bonica, 1990; Berry et al. 1995, Netter, 1991).

The aim of this study was, by using power spectral analysis of heart rate variability, to investigate the effect of acupuncture, applied into the thenar muscle and into the cavum concha of the ear, on sympathetic and parasympathetic activity in healthy persons.

2. Materials and methods

Twelve volunteers, six men and six women, mean age 34.4 (range 23–48) participated in three balanced, randomly distributed sessions. The subjects were recruited via advertisement at the University Hospital of Aarhus. None of the subjects was under medication and none of them had previous experience with acupuncture. Prior to investigation informed consent was obtained. The experimental protocol was approved by the local Ethical Committee.

At an individual initial visit the 12 volunteers were introduced to the concept of 'needle sensation' by having a needle inserted into the point LI 11, located on the end of the lateral transverse elbow crease, when the forearm is flexed 90°. The needle sensation is experienced as numbness, heaviness and radiating paraesthesia (Essentials of Chinese Acupuncture, 1993), a sensation close to deep muscle soreness.

The needle sensation was evoked and the subject was trained to differentiate the characteristic needle sensation from the sometimes pricking sensation when the needle penetrates the skin. Transient pain may be experienced with the needle insertion procedure, however the evoked needle sensation during the stimulation procedure was not associated with pain.

Session A. A short acupuncture needle, (Seirin no 3, $\varnothing 0.20 \times 15$ mm) was inserted perpendicularly into the earpoint, Lu 1, in the left inferior hemi-conchae.

Session B. An acupuncture needle (Hwato, $\varnothing 0.30 \times 30$ mm) was inserted perpendicularly into the Hegu point (LI 4) in the middle of the right dorsal thenar muscle.

Session C. An acupuncture needle (Hwato, $\varnothing 0.30 \times 30$ mm) was inserted perpendicularly superficially (1–1.5 mm) into the skin overlying the Hegu point on the left hand.

2.1. Registration procedure

Subjects were instructed not to eat drink or smoke 2 h prior to treatment. At each of the three sessions, each separated by 24 h, the following procedure took place:

In a supine position the subject was connected to an ElectroCard 2000® (Bang & Olufsen Technology, Struer, Denmark). ElectroCard 2000® is a novel portable battery-driven device for recording ECG signals and subsequent calculation of HRV, PSA and LF and HF components.

Three electrodes were applied: over the right clavicula, over the left lateral rib and over the middle of the lower quadrant of the abdomen. A blood pressure cuff was attached to the patient's left arm and recordings of blood pressure (BP) and heart rate (HR) were made before and after the pre-stimulation period of 15 min, every 5th minute during the stimulation period of 25 min, and every 15th minute during the post-stimulation period of 60 min (Fig. 1).

The ECG signal was continuously recorded by the Electrocard 2000®, and variations in the beat-to-beat intervals, i.e. RR-intervals of the QRS-signal were recorded with an accuracy of 1/250 s. Power spectral analysis of the RR-interval variability was performed using a 1024 point FFT. The LF component was calculated as the power within the frequency range of 0.04–0.15 Hz, and the HF component as the power within the frequency range of 0.15–0.4 Hz (Malliani et al., 1991).

The power of the LF and HF components (ms^2) were calculated separately for the pre-stimulation, stimulation, and post-stimulation periods. These three different time series were each analyzed as a whole. Furthermore, the maximum LF peak power related to each of the five needle stimulations during the stimulation period and the maximal HF peak power related to the first 30 min during the post-stimulation period were calculated on. The peak power of each session was adjusted for different individual baseline power values by dividing the pre-stimulation base-line power of LF and HF, respectively.

In the present study it was aimed to keep the respiration non-controlled to minimize the possible influence on HF and LF values.

2.2. Stimulation procedure

The pre-stimulation period of 15 min was followed by needle insertion. During session A and B the needle

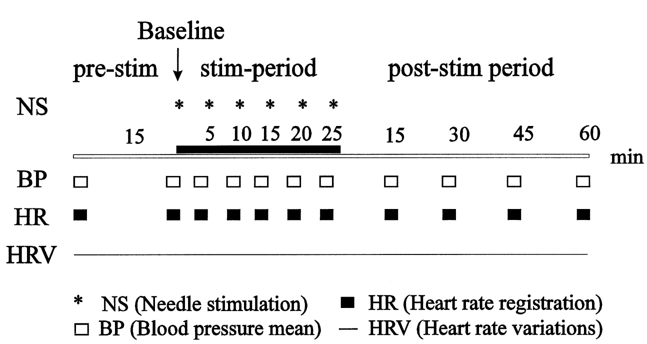

Fig. 1. Study design of the 15 min pre-stimulation period (pre-stim), the 25 min stimulation period (stim-period), and the 60 min post-stimulation period (post-stun period). Marked is the time of needle stimulation (NS, *), blood pressure measurement (BP, □) and heart rate registration (HR, ■). Throughout the whole period ECG with heart rate variability (HRV, −) was measured.

sensation was evoked and recalled every 5th minute during a period of 25 min (Fig. 1).

No needle sensation was evoked during session C. This technique has previously been used in order to evaluate the importance of the needle sensation (Haker and Lundeberg, 1990). To investigate possible changes in blood pressure and heart rate the baseline values were calculated on at the end of the pre-stimulation period of 15 min.

All the data were collected in a data logger and transferred to a computer for subsequent blinded analysis.

2.3. Statistical analyses

The median values of LF and HF power within the stimulation period and the post-stimulatory period were compared to the initial pre-stimulation values, using the Wilcoxon signed rank test. The peak values of LF and HF activity related to needle stimulation were compared using the Mann–Whitney rank sum test. The values of blood pressure and heart rate were compared using paired t-test analysis. $P<0.05$ was considered level of statistical significance.

3. Results

3.1. Heart rate variability– LF and HF activity

No statistically significant differences in LF and HF power during the pre-stimulation period between the three sessions were observed.

Values of the LF and HF power of the stimulation period and the post-stimulation period, were compared with the activity of the pre-stimulation period. i.e. baseline values.

Stimulating the right thenar muscle (session B) caused a significant increase in the LF power during the stimulation period ($P<0.01$), and during the post stimulation period ($P<0.01$), Fig. 2.

Superficial needle insertion in the left thenar muscle (session C) caused a statistically significant increase in the LF power during the post stimulation period ($P<0.01$). Stimulation in the ear (session A) caused no statistically significant changes in the LF power (Table 1).

A significant increase in the HF power was observed both when stimulating the ear and the right thenar muscle during and after the stimulation, $P<0.05$, $P<0.01$, $P<0.001$ (Table 2), Fig. 3.

Superficial stimulation of the skin overlying the left thenar muscle caused a significant increase in the HF power during the post-stimulation period, $P<0.01$ (Table 2).

No significant changes between session A, B, and C in LF peak activity during the stimulation period or in HF peak activity during the post-stimulation period were observed (Table 3).

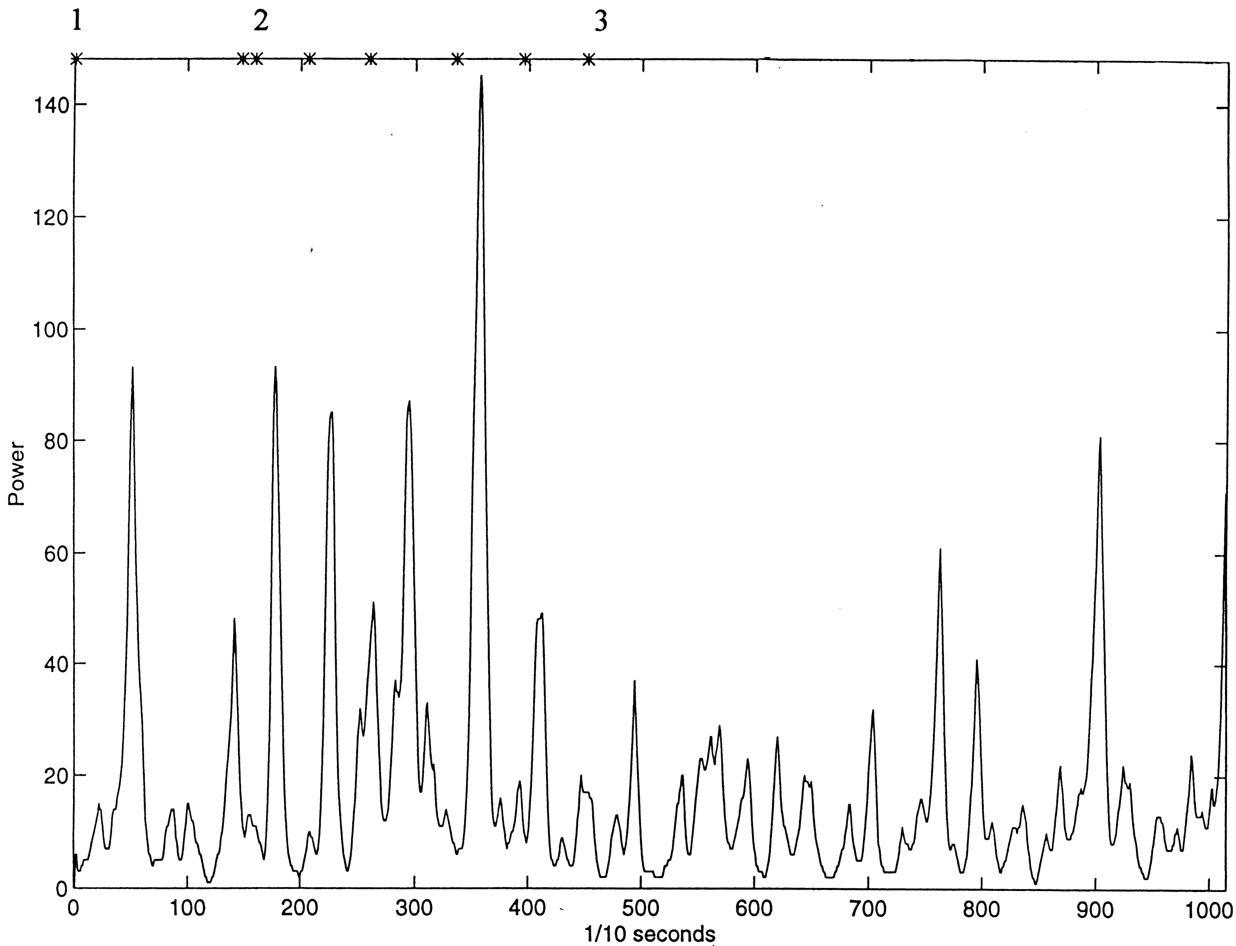

Fig. 2. Stimulation of the thenar muscle. LF power $(ms)^2 \times 10^{-3}$) during pre-stim (1), stimperiod (2) and post-stun period (3). *denote the needle insertion and subsequent stimulations during the stun, period (2).

3.2. Hemodynamics

3.2.1. Initial values.

Initial values of blood pressure and heart rate frequency at the pre-stimulation period at three consecutive sessions regardless stimulation type, were compared. Statistically significant higher diastolic blood pressure was observed at the initial visit compared to visit 2 ($P<0.05$) and visit 3 ($P<0.01$). No significant changes in the systolic blood pressure and heart rate were observed (Table 4).

Table 1
LF power, $(ms)^2 \times 10^{-3}$, when stimulating the left ear, the right thenar muscle, and the skin overlying the left thenar muscle. Values are presented as medians (25th–75th percentiles)

	Pre-stim	Stim	Post-stim
Group A (ear)	0.079	0.104	0.157
	(0.070–0.241)	(0.068–0.237)	(0.134–0.523)
Group B (thenar)	0.091	0.116**	0.150**
	(0.054–0.154)	(0.086–0.297)	(0.107–0.425)
Group C (superficial)	0.087	0.099	0. 137**
	(0.064–0.195)	(0.059–0.227	(0.087–0.253)

** $P<0.01$.

Table 2
HF power $(ms)^2 \times 10^{-3}$, when stimulating the left ear, the right thenar muscle and the left thenar muscle just superficially. Values are presented as medians (25th–75th percentiles)

	Pre-stim	Stim	Post-stim
Group A (ear)	0.063	0.097*	0.119*
	(0.033–0.163)	(0.047–0.234)	(0.070–0.401)
Group B (thenar)	0.062	0.085**	0.096***
	(0.045–0.091)	(0.420–0.320)	(0.056–0.381)
Group C (superficial)	0.093	0.124	0.149**
	(0.59–0.141)	(0.053–0.226)	(0.062–0.300)

* $P<0.05$.
** $P<001$.
*** $P<0.001$.

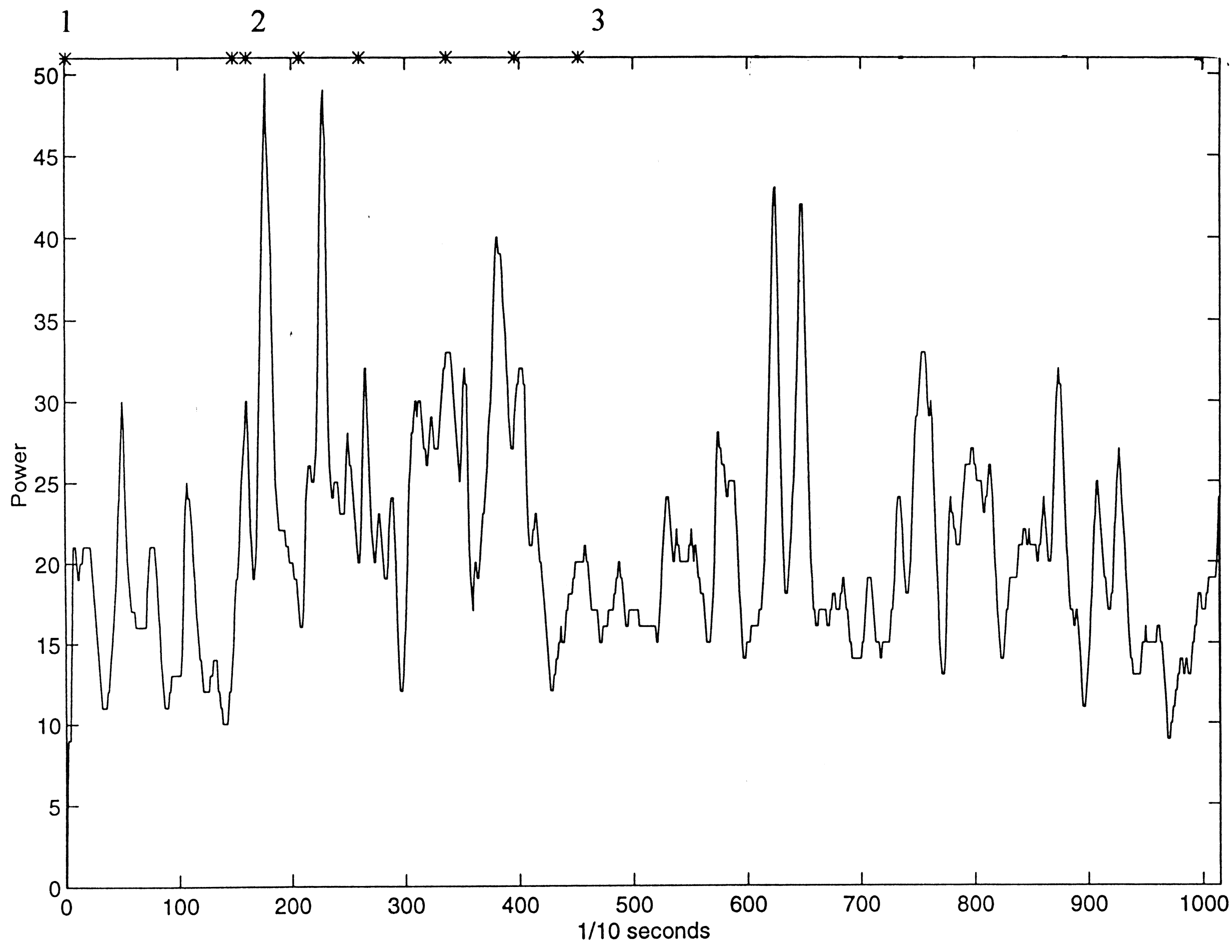

Fig. 3. Stimulation of the thenar muscle. HF power $(ms)^2 \times 10^{-3}$) during pre-stim (I), stim.period (2) and post-stun period (3). *denote the needle insertion and subsequent stimulations during the stun, period (2).

Table 3
Adjusted LF peak activity during the stimulation period and adjusted HF peak activity $(ms)^2 \times 10^{-3}$ during the post-stimulation period. The peak activity was adjusted by dividing with the baseline value, i.e. pre-stimulation value

	LF	HF
Group A (ear)	0.140 (0.070–0.398)	0.125 (0.055–0.415)
Group B (thenar)	0.220 (0.125–0.435)	0.110 (0.045–0.445)
Group C (superficial)	0.140 (0.070–0.255)	0.150 (0.020–0.335)

The median and the 25th–75th percentiles are calculated on.

Table 4
Initial values of systolic (syst) and diastolic (diast) blood pressure (BP), mm Hg, and heart rate (HR), mm^{-1}, at the three consecutive sessions, mean±S.D.

	Visit 1	Visit 2	Visit 3
Systolic BP	127.6±10.4	127.0±14.1	125.3±12.4
Diastolic BP	80.6±9 0	76.4±8.5*	75.8±6.8**
HR	73.2±12.5	70.8±12.7	70.5±8

* $P<0.05$.
** $P<0.01$.

Table 5
Group mean values of systolic (syst) and diastolic (diast) blood pressure, mm Hg, throughout the session

		Pre-stim	Post-stim	End-obs
Group A	Syst	126±9	132±19	122±11
(ear)	Diast	77±7	82 ±15	78±11
Group B	Syst	127±14	128±14	123±15
(thenar)	Diast	74±18	75±9	78±11
Group C	Syst	126±10	125±15	124±12
(superficial)	Diast	78±10	77±11	77±8

Pre-stim: At the end of the pre-stimulation period of 15 min rest, post-stim: After the stimulation period of 25 min, end-obs: At the end of the post-stimulation period of 60 min.

3.2.2. Session values

No significant changes were observed in the systolic and the diastolic blood pressure during the sessions (Table 5), while a significant decrease in HR was observed in session B (thenar stimulation) after the post-stimulation period of 60 min (Table 6).

A summary of the observed changes is presented in Table 7.

Table 6
Group mean values of the heart rate (min^{-1}) measurements throughout the session

	Pre-stim	Post-stun	End-obs
Group A (ear)	70.4±8.4	65.9±11.7	64.7±9.3
Group B (thenar)	71.4±9.7	77.2±13.3	66.8*±8.9
Group C (superficial)	72.4±15.4	66.6±10.6	65.1±9.1

Pre-stim: At the end of the pre-stimulation period of 15 min, post-stim: After the stimulation period of 25 min, end-obs: At the end of the post-stimulation period of 60 min.
* $P<0.05$.

4. Discussion

We found that *stimulation of the ear* induced a statistically significant increase in the HF activity during the stimulation period of 25 min and during the post-stimulation period of 60 min indicating increased parasympathetic activity. No significant changes were observed in either the LF activity, blood pressure or heart rate (Table 7). Our results are in agreement with Zamotrinsky and Karpov, who demonstrated a central vagotonic/sympatholytic influence of the heart rate following electrical stimulation of the ear vagus nerve in patients suffering from coronary artery disease (Zamotrinsky and Karpov, 1997).

Needle insertion in the vagus-innervated part of the ear has also been shown to decrease the concentrations of plasma ACTH and cortisol, likely as a sign of a vagus activation (Wen and Cheung, 1978; Wen et al. 1979). It has previously been suggested that the efficacy of electroacupuncture, in patients suffering from narcotic and alcoholic withdrawal symptoms, applied to the conchae is due to an increased parasympathetic activity (Severson et al. 1977; Mendelson, 1978).

Stimulation of the thenar muscle. A significant increase in both the sympathetic and the parasympathetic activity was indicated in the present study during the stimulation period. Furthermore, an even more pronounced increase in the parasympathetic activity during the post-observation period was observed.

This is an important observation as it has been suggested that the observed increased sympathetic activity during the stimulation period (the short-term response) proceeds into a prolonged sympathetic decrease after the stimulation (the long-term effect) (Sugiyama et al., 1996). The present finding of an increased sympathetic activity during acupuncture stimulation is confirmed by two recent studies (Knardahl et al. 1998; Sugiyama et al., 1996). In these studies it was demonstrated, using microneurography, that both manual acupuncture and electro acupuncture applied to muscle points were associated with increased muscle sympathetic nerve activity in humans.

Heart rate variability (HRV) allows an analysis of the interaction between the activity in the sympathetic and the parasympathetic nervous system by modulation of the heart beat to beat interval. Our results indicate that, when stimulating the thenar muscle, a greatly increased activity in the parasympathetic system during the post observation period is suppressing the jointly increased sympathetic tone, thus resulting in an ultimate increased parasympathetic activity (Table 7). This post-stimulatory enhanced increase in the parasympathetic tone may well explain the ‘transient’ increase in the sympathetic tone, following acupuncture in the thenar muscle, reported by Knardahl et al. 1998.

The superficial needle insertion into the skin overlaying the thenar muscle caused a pronounced significant increase in both the sympathetic and parasympathetic activity during the post observation period of 60 min, whereas no changes were observed during the stimulation period (Table 5). A similar post-stimulatory increased sympathetic activity has also been reported by Knardahl et al. (1998). Nociceptive afferent activity has been demonstrated to occur during ‘pre-pain’ sensations (Kolzenburg and Handwerker, 1994). Therefore, nociceptive activity originating from non-painful stimulation, may be one of the explanations for the increased autonomic activity during the post-stimulation period – a temporal summation of ‘sub-threshold stimulations’.

Table 7
Summary of the observed changes during the trial session

		Stim	post-stim/end obs
Ear	LF (symp.)	–	–
	HF (parasymp.)	↑	↑
	Syst BP	–	–
	Diast BP	–	–
	HR	–	–
Thenar	LF (symp.)	↑↑	↑↑
	HF (parasymp)	↑↑	↑↑↑
	Syst BP	–	–
	Diast BP	–	–
	HR	–	↓
Superficial	LF (symp.)	–	↑↑
	HF (parasymp)	–	↑↑
	Syst BP	–	–
	Diast BP	–	–

The median values of LF and HF power $(ms)^2 \times 10^{-3}$ during the stimulation (25 min) (stim) and during the post-stimulation period (60 min) (post-stim) are used to visualize changes in the sympathetic (symp) and parasympathetic (parasymp) activity while the values of blood pressure (BP) and heart rate (HR) denote the values after the stimulation period and after the post-stimulation period (end obs). ↑,↓, $P<0.05$; ↑↑, $P<0.01$; ↑↑↑, $P<0.001$.

4.1. Hemodynamics

Stimulation of the thenar muscle resulted in a statistically significant decrease of the heart rate at the end of the post-stimulation period. This is in line with the findings of Sugiyama et al. (1995), who reported a cardiosuppressive effect following acupuncture. They suggested that the effects were due to the activation of the parasympathetic cholinergic system, which is further supported by the present indication of elevated parasympathetic activity in the post-stimulation period.

No matter what stimulation techniques or sites of needle insertion used, the blood pressure remained unchanged throughout the present study. Previous studies have demonstrated contradictory results when measuring the blood pressure during and after needle stimulation (Knardahl et al. 1998; Sugiyama et al., 1995). Different stimulation techniques may explain these differences.

4.2. HRV

The heart rate variability (HRV) technique has previously been used to demonstrate the influences of different body positions (Pomeranz et al., 1985) and the influence of various anaesthetics (Widmark et al., 1998) on the autonomic nervous system.

Frequency fluctuations in the range of 0.04–0.15 Hz (LF) are, however with some controversy, considered to be a marker of sympathetic activity, and high frequency fluctuations in the range of 0.15–0.40 Hz (HF) are considered a marker of parasympathetic or vagal activity (Task Force on the European Society of Cardiology, 1996). A reciprocal relation exists between these two frequency domains and is similar to that characterizing the sympathovagal balance (Malliani et al. 1991).

4.3. Methodological considerations

It seems reasonable that a subject exposed to an experimental trial to some extent will be subjected to anxiety, stress, or fear, which likely influence the sympathetic activity. Dyrehag et al. (1997), demonstrated that perceived stress during somatic afferent stimulation constitutes a negative factor to the analgesic effect.

In the present study we tried to avoid any psychological and physical stress by introducing the subjects to the experimental procedure at an initial visit during which they were informed about the design of the trial. They were also subjected to the three modes of stimulation. It is reasonable to suggest that the subjects might be more experienced to the procedure at visit 3 as compared to visit 1, which may explain the significant decrease in the initial values of the diastolic blood pressure observed in our study at visit 3 (Table 4).

It is impossible to perform a double-blind study involving acupuncture. As an identical experimental procedure is crucial for the achievement of identical psychological input (Vincent and Richardson, 1986), no subject was observed without needle insertions. The superficial needle insertion technique was presented in 1990 (Haker and Lundeberg, 1990) and was considered as a technique of control. Recently, a placebo acupuncture needle has been introduced to simulate an acupuncture procedure without penetrating the skin (Streitberger and Kleinhenz, 1998). Kept in a tube, the placebo needle is not fixed inside the copper handle. Its tip is blunt, and when it touches the skin a pricking sensation is felt by the patient, simulating the puncturing of the skin. However, despite no skin penetration the tip exert a mechanical stimulation and according to the results presented by Kolzenburg and Handwerker (1994), a non-painful mechanical stimulation may induce an increase of the cutaneous blood flow and may also excite nociceptive primary afferents. To conclude, no ideal method of placebo stimulation involving acupuncture exist at the present time.

5. Summary

The present results indicate that acupuncture induces a significant increase in the HF component of HRV reflecting parasympathetic activity following acupuncture. Possibly, this explains the relaxation, calmness and reduced feelings of distress commonly experienced by the patients.

To achieve these reactions the following modes can be used: 1. Stimulation of the vagal innervated part of the ear (immediate effect), 2. Stimulation of muscle points (delayed effect).

6. Conclusion

It is concluded that sensory stimulation (acupuncture) is associated with changes in HF and LF components of HRV reflecting changed balance between the sympathetic and parasympathetic system depending on site of stimulation and period of observation.

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