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Physiological and psychological correlates of attention-related body sensations (tingling and warmth)

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Body sensations play an essential role in the subjective evaluation of our physical health, illness, and healing. They are impacted by peripheral somatic and external processes, but they are also heavily modulated by mental processes, e.g., attention, motor control, and emotion. Body sensations, such as tingling, numbness, pulse, and warmth, can emerge due to simply focusing attention on a body part. It is however an open question, if these sensations are connected with actual peripheral changes or happen "only in the mind." Here, we first tested whether the intensity of such attention-related body sensations is related to autonomic and somatomotor physiological processes and to psychological traits. In this study, attention-related body sensations were not significantly connected to changes in physiology, except warmth sensation, which was linked to decrease in muscle tension. Overall intensity of tingling significantly correlated with body awareness and tendentiously with body–mind practice. This strengthened the hypothesis that attention-related body sensations are more the result of top–down functions, and the connection with peripheral processes is weak. Here, we suggested a novel protocol to examine the effect of manipulating attention on body sensations, which together with our results and discussion can inspire future researches.

Keywords: psychophysiology, body attention, body awareness, tingling, body sensation

Introduction

Full understanding of how we perceive our body through the interoceptive system seems problematic, since there is a growing body of evidence demonstrating that various body sensations can be experienced even in the complete absence of obvious physiological changes or external manipulation. Such sensations were reported in various experimental studies, which explored, e.g., placebo treatment (10), sham electrical (26, 41) or vibratory tactile stimulation (38), verbal suggestion (55), and even mere attentional focus on a body part (36). Self-consciousness theory states that introspection intensifies perceived internal states, e.g., body sensations, emotions, and motives, which lead to a more accurate self-perception (15). This latter idea, also called *veridicality* ("*veracity*") or *perceptual accuracy hypothesis* (24), however, was not supported by empirical findings (54). For example, the perception of body arousal, similar to other forms of perception, is impacted by various biases and top–down influences, e.g., false physiological or verbal feedback (1, 13, 16, 17, 25, 39, 44, 62, 64). In

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other words, only the neuronal representation of arousal is experienced consciously, and not arousal *per se* (18). The same holds true for the experience of body processes and symptoms; as they represent the conscious outcome of a complex perception process, they are often not or just weekly connected to elementary sensory events (32, 33, 35, 46–48, 52).

Here, we will examine body sensations, such as tingling, numbness, pulse, and warmth, which emerge during simply focusing attention on a body part (36). We will refer to this phenomenon briefly as attention-related body sensation. Regarding the psychophysiological background of attention-related body sensations, three independent but possibly interacting mechanisms are conceivable. First, there is a constant spontaneous activation of the interoceptive sensory neurons stimulated by basic peripheral physiological fluctuation, or ectopic activation of peripheral, and more importantly, central sensory neurons. This activity is usually filtered out to liberate attentional resources, but attention can let it pop out and reach consciousness (12, 36, 42). Further mental processes were suggested to exert an effect on attentional filtering and thus modulate body sensations, such as expectation (46), motivation (63), decision-making (27), and emotion (56). For example, expectations of given body changes are able to shape low-level (i.e., non-conscious) filtering processes; those components of spontaneous fluctuations (i.e., noise) that are in accordance with the expectation will be further processed and interpreted as actual changes (i.e., signal), whereas contradictory information will be rejected (21, 45, 46, 50, 51). Such top–down modulation can happen within the brain or even at the spinal level (53).

The second possible mechanism of the psychophysiological background of attention-related body sensations is that top–down processes activate somatosensory representations even in the total absence of any bottom–up information, i.e., they can be of purely central origin (10). This is supported by the model of "as if body loop," a cerebral circuit that starts from the ventromedial prefrontal cortex, activating the secondary and primary somatosensory cortex, insula, and even brain stem nuclei, which results in the central simulation of peripheral events (9).

The third possible mechanism is that body attention impacts the motor coordination and/or affective state, which in turn changes the state of peripheral tissues through the somatomotor and the visceromotor nervous system. It is well known that emotions are strongly connected to body sensations (43) and recently it was also found that motor activation is able to alter (typically inhibit) body sensations (8). It is possible that attentional focus on a body part either brings into consciousness, a memory or thought connected with the body (part), which triggers emotions and autonomic responses, or helps noticing a muscle tension and relax it, by which previously filtered sensations are disinhibited.

Personal differences regarding attention-related body sensations were also found. Those with higher interoceptive accuracy as assessed by a heart-rate detection task reported more sensations (37). Different dimensions of attention, i.e., the role of interoceptive sensitivity, effortful and sustained attention, and selection of relevant information were also suspected to contribute to attention-related body sensations (40), while in a later study, interoceptive awareness was indeed found to be connected to attention-related body sensations, but such connection was not found with performance in a sustained attention task (61). Only one study has experimentally discovered the psychophysiological background of attention-related body sensations to our knowledge, solely examining central physiological processes. This functional magnetic resonance imaging (fMRI) study demonstrated that the attentional focus on either thumb increased the connectivity between the primary somatosensory cortex and the superior frontal gyrus, and the anterior cingulate cortex (7), and the subjectively rated attentional strength correlated with the activation of the ventral frontopolar prefrontal cortex, whereas the experienced intensity of the sensations correlated with the activation of the dorsal frontopolar prefrontal cortex, and *inter alia* the primary somatosensory cortex, insula, and amygdala (6). In an fMRI study, body attention activated even spinal areas in expert practitioners of a body–mind method; however, body sensations were not characterized there (29).

Once a body sensation reaches consciousness, even if it was evoked by attention and originated centrally, different meanings, causes, and consequences can be attributed to it. A negative interpretation (e.g., label the sensation as a symptom of disease) can form a vicious circle with hypervigilance, where attention, expectation, and emotion worsen the complaints through a process called somatosensory amplification (3, 5). Moreover, it might even lead to the subjective experience of being sick in the absence of either any somatic pathology (medically unexplained symptoms and idiopathic environmental intolerance; 4) or harmful factors (nocebo effect; 31, 57, 58). On the other hand, a positive feedback loop can also be activated, when a body sensation is interpreted in a positive way (e.g., as a sign of healing), which can lead to positive expectations, enhance placebo effect, and contribute to trust in therapy, compliance for and effectiveness of it (10). Besides therapeutic effects, body sensations can also have hedonic value in processes of recreation and entertainment (11, 60). Moreover, they were suggested to play an essential role in self-awareness (36), the overall perception, and evaluation of body condition (20).

In sum, the clinical and psychological relevance of the attention-related body sensations (e.g., medically unexplained symptoms, placebo effect, recreation, body-awareness, and self-consciousness) is high. In complementary and naive discourse, it is often emphasized that body attention can initiate acute physiological changes at the site of attentional focus, which can help therapeutic processes, and that this attention-induced self-healing can be strengthened by various body–mind exercises (e.g., yoga and autogenic training; 10). However, the experimental testing of these hypotheses is missing.

Here, we first tested whether the intensity of attention-related body sensations is related to autonomic and somatomotor physiological processes, or to psychological traits and body–mind practice. Since body sensations were hypothetically linked to tonic motor activity, the autonomic nervous system, the motor system, and body temperature (26), our questions were as follows: how is the intensity of different attention-related body sensations related to muscle tension (as assessed by electromyography), to parasympathetic activation [as assessed by heart-rate variability (HRV)], to sympathetic activation (as assessed by skin conductance), and to local temperature at the point of attentional focus? And since attention-related sensations were linked to interoceptive accuracy by an empirical result (37), and to experience with a body–mind method by theoretical investigations (10), here, we hypothesized positive connections between the intensity of the attention-related body sensations, body awareness, and the regular practice of body–mind method.

Materials and Methods

Participants and experimental setting

Right-handed, healthy university students with no injury at the target locations ($n = 27$, 11 males, age $= 22.0 \pm 2.01$ years) were participated in the approximately 12-min-long experiment between 9 a.m. and 6 p.m. The experiment took place in a silent laboratory room tempered to 24 °C. Participants were asked one by one to lie down on their back on the

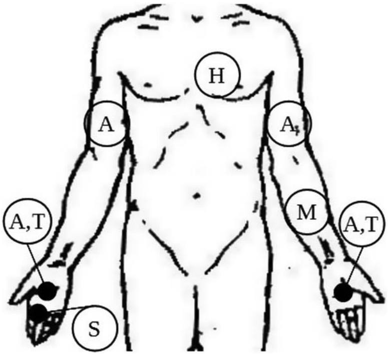

Fig. 1. Sites of attentional focus and physiological measurements: A = attentional focus, T = local temperature measurement, M = electromyographic measurement, S = skin conductance measurement, H = electrocardiographic measurement

experimental table with closed eyes, arms stretched near to the body with palms up. Before the experiment, electrodes were positioned on the subjects for the measurement of various physiological variables (see "Measurements" section), and the attentional sites were linked for local temperature measurement during the experiment. Then, through headset, we played an audio record, which guided participants to focus their attention on four different body parts (palm and upper arm on both sides, altogether four periods, also see Fig. 1) for 60 s each, in a randomized order. Attention periods were separated by 30-s-long resting periods. The entire attention section was preceded by a 90-s-long baseline period and followed by a 90-s-long end-line period. Following the end-line period, written feedback was requested about the experienced body sensations.

No prior suggestion was given about concrete sensations that might be felt (e.g., tingling), participants were informed only that the goal of the experiment was the exploration of the psychophysiological effects of paying attention to the body, which sometimes reveals different sensations and sometimes not. Moreover, as an introduction to each attention period, the audio guide asked the participants to direct their attention at the body part in question, and be aware of the sensations actually felt there. Trait-like psychological characteristics (see below) and experience of body–mind practice (see below) were assessed before the experiment. The study was approved by the Research Ethics Board of the Faculty of Education and Psychology, ELTE Eötvös Loránd University. All participants signed an informed consent form before participating in the experiment.

Measurements

Characteristics of body sensation. After the end-line period, participants were asked to write down the following aspects of their experiences with respect to each attention period separately: (1) type of the sensation(s) (no examples were given for participants), (2) intensity from 1 to 10. In the analysis, we used any body sensation label (e.g., "tingling" or "warmth") only if that was the exact description used by the subject. Similar or related descriptors were separately treated. In the cases of not reporting a body sensation, we scored the intensity "0."

Physiological variables. Skin conductance (right hand, palmar surface of the first phalanges of the second and third finger), electromyographic activity (on proximal and distal end of the palmar surface of the left forearm), and HRV (root mean square of the successive differences values extracted from data of three channels: right and left clavicle, and iliac crest) were continuously recorded using the NeXus-10 MKII (Mind Media, Herten, The Netherlands) system (see Fig. 1). Local temperature of the hand in focus was manually measured every 15 s using an infrared non-contact thermometer gun (model: DT-8806C) 0, 15, 30, 45 s after and right before the attentional instruction as well.

The 19-item *Somatic Absorption Scale* was developed by David Watson to assess the proneness to continuously monitor interoceptive processes (e.g., posture, heartbeat, and bodily changes caused by sport or meal) on a 5-point Likert scale. It estimates a non-evaluative (i.e., free of negative affect), everyday aspect of body awareness, free from strong negative body experiences (pain and catastrophization). The Hungarian version of the scale was proved to be valid and showed good internal consistency (Cronbach's $\alpha = 0.84$) in a previous study (30). Its Cronbach's α coefficient was 0.80 in this study, mean score was 64.2, and standard deviation was 9.04.

Body–mind practice. The current body–mind practice (e.g., autogenic training, relaxation, yoga, tai chi, meditation, and contact dance) was assessed by the estimated average length (minutes) of such practices in a week.

Data analysis

Physiological data obtained (electrodermal activity, electromyogram, and electrocardiogram) were processed by the BioTrace^{+} software (V2014A UK). Mean values for the first 45 s of the attention and baseline periods were calculated, and then mean values were controlled by subtracting the mean value of the 45-s-long phase directly preceding the measurement (either baseline or another attention period due to randomization). Local temperature values were also averaged for the first 45 s, and controlled by subtracting the temperature measured right before the attentional instruction. Data analysis was conducted using the SPSS v21 software. Since most of the subjective ratings of body sensation were non-normally distributed, non-parametric correlations (Spearman's ρ) were used to estimate the relationships between attention-related body sensations, autonomic and somatomotor physiological processes, and psychological characteristics. Correlations between intensity of perceived sensation on the left palm and muscle tension measured on the left forearm were estimated. Similarly, connections between intensity of perceived sensation on the right palm and skin conductance on the same location were calculated. In the case of local temperature and HRV, connections with sensations for both sides were investigated. Since we did not have predictions regarding the direction of connections between physiological variables and attention-related sensations, significances were calculated with two-tailed test. On the contrary, since we hypothesized positive connections regarding body awareness and body–mind practice, significances were calculated with a one-tailed test. In all cases, correlation values were controlled for gender using the procedure described by Conover (19). Statistical significance was determined using Bonferroni-corrected p values; corrections were separately calculated for physiological (12 trials) and psychological (4 trials) variables. Degrees of freedom were 24 for every partial correlational analysis.

Results

Descriptive statistics

Tingling was experienced by 14 subjects (approximately 58% of participants; in total, 24 times out of the 108 cases), and warmth was experienced by 10 subjects (approximately 42% of participants; 21 times out of the 108 cases). Other sensations were apparent with such a low frequency (see Table I) that they could not be statistically analyzed. Therefore, here, we

Table I. List and frequency of attention-related body sensations, separately in the four locations and in total

	Right palm	**Left palm**	**Right arm**	**Left arm**	**Total**
Tingling	6	9	3	6	24
Warmth	7	5	5	4	21
Numbness	3	6	2	1	12
Heavy	1	1	1	2	5
Cold		1	2	2	5
Pulse			2	1	3
Sting	1	1		1	3
Radiate	1	1	1		3
Throbbing	2				2
Calm		1	1		2
Pain			1	1	2
As if be touched				2	2
Circulation		1			1
Pressure			1		1
Pleasant feeling		1			1
Effervescence		1			1
Twitch		1			1
Tense				1	1
Tiredness				1	1
Simply felt the body part/not specified	1		1	2	4
No sensation reported	9	5	8	7	29
Tingling and warmth together	2	2	1	2	9

focused on the two most often mentioned sensations, tingling and warmth. The intensity of tingling and warmth was valued as “0” when not specifically this sensation was reported, i.e., the intensity of tingling and warmth was “0” in 84 and 87 cases (approximately 78% and 81% of total cases), respectively. Descriptive statistical data of the assessed scales are presented in Table II.

Correlation analysis

Muscle tension measured during the period of focusing on the left forearm was tendentiously and inversely linked to the intensity of perceived warmth in the left palm (Spearman’s $\rho = -0.50$, $p = 0.009$, Bonferroni-corrected $\alpha_{10\%} = 0.0083$ and $\alpha_{5\%} = 0.0042$ in the 12

Table II. Descriptive statistics (mean and standard deviation) of the variables, psychological, and physiological variables for each attention site separately, physiological variables with uncontrolled and controlled values

	Right palm	**Left palm**	**Right arm**	**Left arm**	**Average**
Tingling intensity	1.5 ± 2.99	2.2 ± 3.36	0.4 ± 1.21	1.3 ± 2.60	1.3 ± 1.85
Warmth intensity	1.6 ± 2.89	0.8 ± 2.36	1.0 ± 2.34	0.9 ± 2.40	1.1 ± 1.77
Muscle tension (mV), uncontrolled	–	137.0 ± 476.89	–	–	–
Muscle tension (mV), controlled	–	131.5 ± 475.55	–	–	–
Skin conductance (μS), uncontrolled	7.4 ± 6.59	–	–	–	–
Skin conductance (μS), controlled	−0.5 ± 1.79	–	–	–	–
Local temperature (°C), uncontrolled	35.9 ± 1.11	35.8 ± 1.15	–	–	–
Local temperature (°C), controlled	−0.03 ± 0.41	0.04 ± 0.23	–	–	–
Heart-rate variability, uncontrolled	118.8 ± 98.01	102.4 ± 86.25	–	–	–
Heart-rate variability, controlled	17.7 ± 50.88	−3.7 ± 64.17	–	–	–

correlational analyses of physiological data), but not to perceived tingling ($\rho = -0.11$, $p = 0.6$). Skin conductance in the right palm showed no significant correlation with tingling ($\rho = -0.20$, $p = 0.3$) and warmth in right palm ($\rho = 0.21$, $p = 0.3$). Local temperature measured on the right palm was not connected with tingling ($\rho = 0.044$, $p = 0.8$) and warmth in right palm ($\rho = -0.41$, $p = 0.04$). Similarly, local temperature on the left palm was not related to tingling ($\rho = 0.10$, $p = 0.6$) or warmth in the left palm ($\rho = 0.082$, $p = 0.7$). Finally, HRV measured during attention on the right palm was not connected to tingling ($\rho = -0.073$, $p = 0.7$) and warmth in the right palm ($\rho = 0.12$, $p = 0.6$), and HRV during attention on the left palm did not correlate with tingling ($\rho = -0.10$, $p = 0.6$) or warmth in the left palm ($\rho = -0.05$, $p = 0.8$).

Body awareness showed a medium-level correlation with the average intensity of tingling (Spearman's $\rho = -0.48$, $p = 0.006$, Bonferroni-corrected $\alpha_{10\%} = 0.025$ and $\alpha_{5\%} = 0.0125$ for the four correlational analyses) but not that of warmth ($\rho = 0.16$, $p = 0.21$). Body–mind practice showed a tendentious correlation to the intensity of tingling, but not to warmth ($\rho = 0.39$, $p = 0.024$ and $\rho = 0.21$, $p = 0.15$).

Discussion

In this study, attention-related body sensations, more accurately, tingling and warmth, showed no connection with local (electrodermal activity and skin temperature) and systemic (HRV) physiological changes. Attention-related warmth sensation was connected to decreased muscle tension. Overall intensity of tingling, as opposed to warmth, correlated significantly with body awareness, and tendentiously with body–mind practice. Overall, this pattern supports the hypothesis that attention-related body sensations are mainly generated by top–down processes, possibly interacting with peripheral processes.

The presence of tingling as the most frequent attention-related sensation is in accordance with previous results, while warmth had been preceded by other sensations previously (e.g., numbness, beat/pulse, and itch; 12, 36). In "Introduction" section, we proposed three alternative explanations for such frequent occurrence of body sensations in the absence of stimulation: (1) there is a constant background activity in the sensory neurons (caused by peripheral physiological fluctuations or ectopic neuronal activation), (2) attention activates central interoceptive (somatosensory and visceroceptive) representations, and (3) focusing on the body initiates thoughts, emotions, or homeostatic regulation, which changes peripheral physiology and activates sensory neurons.

The inverse connection between warmth and muscle tension found here is in line with previous results showing that attention-related body sensations were blocked by movement (8). It was suggested that the suppressive effect of muscle contraction on tingling and other body sensations might be mediated by top–down masking at cortical and spinal levels (8), and by muscle afferents at the spinal level (59). It is also possible that the warm sensation helped our participants to become aware of previously hidden muscle tension in this area, and release it, although it seems contradictory that tingling did not have this effect. In addition to this inverse connection between somatic sensations and muscle tension, as warmth was thought to be linked to better circulation, decrease in muscle tension might cause increased local circulation by lowering the obstructive physical pressure exerted by a contracted muscle.

Local temperature, which is mainly determined by dermal circulation regulated by the sympathetic nerves (28), showed no connection to body sensations, although increased circulation was thought to be linked to tingling and warmth (49).

Skin conductance, an indicator of sympathetic activation, and HRV, an indicator of parasympathetic activation, were neither connected to the intensity of body sensations. Previous findings on the connection between somatic sensations and sympathetic/parasympathetic activation are inconsistent. On the one hand, increase in sympathetic activation was linked to paresthesia (e.g., tingling) and hyperesthesia (mostly hyperalgesia) in some disorders, e.g., in fibromyalgia syndrome and complex regional pain syndrome (34), whereas parasympathetic activation was linked to the suppression of body sensations (mostly in the case of pain and itch; 14, 65). On the other hand, a balance between sympathetic and parasympathetic activation (typically increased parasympathetic and decreased sympathetic activity) was thought to be a criterion of being aware of body sensations (23). Our results suggest that in healthy individuals, attention-related body sensations were not connected to autonomic activation or such activity could not be detected in the short 1-min-long periods using our methods.

Self-reported body awareness was connected to the average intensity of tingling during the experiment, which is in line with the concept of body awareness, i.e., the tendency to focus attention on and perceive somatosensory signals (30), and with the concept that top–down processes have a strong impact on interoception (9). Warmth showed no connection to body awareness; maybe this connection was hidden by the uncontrolled variance of bottom–up processes, e.g., physiological fluctuation in temperature, while tingling was caused by a more constant physiological background activation (36).

Body–mind practice did not show connection to the intensity of warmth, and showed only a tendentious connection to tingling. Such practice was thought to create a positive expectation toward situations of body attention (2), which are believed to help the attunement of real experience about self and ideal expectations (22), and the enhancement of self-regulation (23). Perhaps this connection could be better examined in a sample of more expert body–mind practitioners.

Here, we suggested a novel experimental protocol to examine attention-related body sensations, with numerous differences compared with earlier protocols, namely the "spontaneous sensation" protocol (36). First, we avoided to give any concrete example of body sensations to be felt or any instruction to actively search for them. Second, we gave longer time to experience body sensations while focusing on a body part, 60 s instead of 15 s. The reason of this was that according to a recent pilot study, body sensations emerge 20–40 s after the instruction (7). Moreover, our subjects were asked to lie down, close the eyes, and avoid moving, to reduce noise in physiological recordings, equally to the fMRI study on attention-related body sensations (7). The supine posture might reduce the generalizability of the results to everyday situations (e.g., except relaxation or hospitalized patients), but it is also controlled for the variability among participants to be able to sit for ca. 12 min in comfort. Unfortunately, we did not test how the closely applied electrodes change body sensations (generation, alteration, and suppression); it is a task to be performed to explore the effect of an fMRI measurement on body attention and related sensations. Further studies are needed to compare the differences between these protocols, and also to involve the significant factors identified in the studies of spontaneous sensations, namely laterality, the availability of visual input from the body part in focus, and also explore the sensations emerging outside of the area in focus. Here, the absence of comparing skin conductance results from left and right body parts (since the left hand had been found to be more sensitive) and of including cases with visual input versus closed eyes (visual input could foster body sensations) could possibly contribute to the minimal significant results.

Since the procedure applied here to have enough cases for our statistical analyses, namely to value the intensity of tingling and warmth as "0" when no such sensation was reported, could possibly cause distortions in the results, a larger sample would be needed to run the correlational analyses between a reported sensation and physiological variables only in cases when the sensation was reported. A larger sample would also allow us to analyze the other types of sensations excluded here, and to compare the cases when a sensation was reported versus not reported, or the subjects who reported versus not reported any sensations.

We are aware of further limitations of this study and thus for future researches, we also recommend to involve (1) the prior expectations of the subjects regarding body sensations caused by body attention; (2) the nervous system, either centrally (electroencephalography and fMRI) or peripherally (electroneurography); (3) more detailed temporal (onset and endurance) and spatial (area and direction) characteristics of the subjective body sensations; (4) subjective interpretation, e.g., beliefs about the causes or the effects of the sensations; (5) affective state before (and after) the test, and the hedonic value of body sensations; (6) state sleepiness and biorhythm; (7) effect of social desirability on reports; and (8) longitudinal design to explore the effect of an intervention with a body–mind method.

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