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Bodily maps of exercise-induced feelings

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Physical exercise is a strong physiological and mechanical stimulus that elicits various bodily sensations. They shape the emotional experience and contribute to the psychological benefits of exercise. Despite the centrality of subjective sensations stemming from altering bodily states during physical exercise, there is a paucity of data on bodily experiences and sensations evoked by physical exercise. Here, we mapped bodily sensations evoked by exercise in two studies. In the first proof-of-concept study, we asked participants ($n = 305$; 143 females) to imagine undergoing exercise training and report the expected bodily sensations. In the second field study, we mapped participants' ($n = 133$; 105 females) emotions and bodily sensations before and after actual exercise sessions. Both studies utilised visual analogue scales for sensation rating and a topographical self-report tool for mapping bodily sensations: participants were asked to colour on a human body silhouette all the bodily regions where each specified sensation (e.g. "Energized") was felt. The findings revealed a wide array of exercise-induced bodily sensations with mostly distinct topographies, that were consistent across individuals. The field experiment confirmed that bodily sensations of activeness and exhaustion intensified following exercise in topographically specific manner, and that the experience of exhaustion in the body mapping was linearly associated with physiological (heart rate) and subjective (rating of perceived exertion) indices of exertion. Altogether, these results show that different exercise-induced sensations have distinct bodily topographies and suggest that body sensation mapping might provide a novel approach for measuring exercise-induced emotional experiences and aid in planning exercise and recovery schedules.

Keywords Emotion, Physical exercise, Somatosensation, Affective experience, Body mapping

Bodily sensations and emotions are an inherent part of physical exercise. Exercise is a strong physiological and mechanical stimulus that elicits changes throughout the biological circuits in the body. These physiological changes – including increased heart rate, respiration, muscle activation, and thermoregulation – are conveyed to consciousness via interoceptive pathways and contribute to how individuals experience exercise. Being aware of the physiological and biomechanical state of the body helps to regulate exercise performance and also shapes the emotional experience of exercise[1–3]. Exercise is an effective behavioural strategy for self-regulation of mood and emotions[4–8], and consequently, it is also beneficial for improving symptoms of depression, anxiety, and psychological distress[9].

Emotions are tightly intertwined in the body, as they adjust behavioural priorities, central nervous system states, skeletomuscular systems, and autonomic activity to promote survival and well-being[10]. Many classic and modern emotion theories also posit that the subjective experience of emotions (e.g., 'I feel good') is shaped by interoceptive and somatosensory feedback from the current bodily state[11–13]. Different emotions as well as cognitive and somatic states have discernible and consistent "feeling signatures" in the body[13–15]. These findings are based on distinct topographical maps derived from simple self-reports of phenomenological bodily sensations to demonstrate how basic and more complex emotions are represented in the body. Importantly, the greater the emotional intensity of a mental or somatic state – whether towards pleasure or displeasure – the more strongly it is experienced in the body[14], highlighting the embodied nature of emotions.

Exercise-evoked emotions predict long-term exercise engagement[16,17]. While exercise is typically associated with mood elevation, the spectrum of feelings, sensations, and emotional states induced by exercise is complex, ranging from anger and disgust[18] to the invigorating euphoria of a "runner's high"[19,20]. These emotional responses are modulated by interoceptive bodily signals, such as increased heart rate or muscle fatigue, which, together with cognitive appraisal, influence whether these sensations are perceived as energising or distressing, and thus, whether they motivate or discourage future exercise. Positive emotions, such as joy and pleasure,

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act as positive reinforcers that promote exercise motivation and maintenance of regular exercise routines[21–26], whereas negative emotions and sensations, such as shame and pain, act as negative reinforcers that may lead to exercise avoidance[27]. For example, an increased heart rate may be interpreted as invigorating or overwhelming, depending on an individual's interoceptive accuracy, interoceptive sensitivity, and prior experiences. Negative feelings may be particularly relevant when adopting a new exercise routine, as discomfort and pain are common when transitioning from a sedentary to an active lifestyle. However, strict adherence to an exercise program can rapidly shift even initially negative exercise-induced feelings to positive, thus promoting exercise motivation[21,28,29]. Moreover, positive mood is associated with greater likelihood of exercising, which in turn results in improved mood, creating a positive loop[30,31].

Muscles generate power and heat during exercise, and the associated metabolic changes, alongside with the accumulation of lactate and other muscle metabolites, lead to sensations and feelings of fatigue and exhaustion in both the muscles and in the mind[32]. By altering the physiological processes that may subsequently be conveyed to consciousness via interoceptive pathways, exercise results in various sensations such as sweating, cramping muscles, a pounding heart, feeling "the buzz", "the pump", and pain, all of which shape the overall emotional experience of exercise[2,33]. Consequently, interoceptive processing of the bodily signals plays a central role in linking bodily states to self-regulation and emotional responses[34]. The brain interprets interoceptive signals in conjunction with cognitive appraisals, leading to individual differences in how bodily sensations are experienced[35]. Bodily sensations refer to direct perceptual experiences arising from physiological states (e.g., warmth, muscle tension, fatigue), whereas feelings integrate these sensations with cognitive and emotional appraisals (e.g., feeling strong, exhausted, or energised). While both are influenced by interoceptive processing, bodily sensations may provide immediate physiological feedback, whereas feelings reflect a subjective interpretation shaped by prior experiences and psychological factors.

Bodily sensations are particularly relevant in the context of exercise, where interoceptive cues such as heart rate, respiration, and muscular fatigue can be experienced as either motivating or aversive, depending on individual differences in interoceptive awareness and emotional appraisal[36,37]. For instance, sensations of exertion may initially be unpleasant but can, through repeated exposure and positive reinforcement, become associated with a rewarding sense of accomplishment. As a result, even discomfort or pain may ultimately trigger positive feelings that enhance exercise engagement[2,33].

Despite the centrality of interoception and somatosensation in generating subjective sensations and the capacity of physical exercise to alter bodily states, there is a paucity of data on bodily experiences and sensations evoked by physical exercise. Understanding the topographical patterns of the exercise-evoked sensations is important, as sensations in specific areas, such as chest tightness or discomfort in the lower back, may be perceived as distressing or harmful, potentially leading to anxiety and avoidance of exercise[36]. Conversely, sensations in "the right place", such as burning muscles in the limbs, may signal competence and goal-aligned progress which can enhance confidence and motivation[33,37,38]. Over time, these patterns contribute to learning and embodied familiarity with exercise, helping individuals distinguish between healthy strain and potential overexertion[37,38]. By identifying where sensations are felt and how they are interpreted, body mapping may help to refine exercise routines, improve communication between clients and professionals, and support adherence through better understanding of one's own bodily experiences.

Visual body mapping tools allow individuals to indicate precisely where they feel sensations, providing a more detailed and intuitive account of the bodily experience than verbal checklists alone. The body mapping method captures not only whether a sensation is present, but also its distribution and extent, which can reveal patterns that are difficult to articulate with words[39,40]. Body mapping has been widely used in pain research to assess both the location and quality of pain sensations and has shown value in clinical settings for identifying symptom patterns that may guide diagnosis and treatment[41,42]. Interestingly, recent findings indicate that when given the option, individuals often choose specific qualitative descriptors (e.g., burning, dull, stabbing) instead of the general term "pain" when creating body maps of pain symptoms[41,42]. This suggests that bodily sensations are often multidimensional and not easily reduced to single labels, highlighting the added value of body mapping for capturing nuanced subjective experiences. Extending this approach to emotion and exercise research can help uncover similarly multifaceted patterns in feelings and sensations like exhaustion, invigoration, or discomfort, which may otherwise go undercharacterised in traditional verbal or checklist-based assessments. Therefore, body mapping can complement traditional tools by offering a richer representation of the subjective experience, which may be valuable not only in research but also in applied settings such as personal training, physiotherapy, or app-based self-monitoring systems.

Here, we mapped bodily sensations evoked by physical exercise using two different self-reporting approaches: conventional visual analogue scale responses for different somatic sensations (e.g. active, strong, relaxed) and using a topographical self-report tool – applied here for the first time in an exercise setting – where the subjects indicated on a blank human body where they experienced each of the sensations[13,14]. In the first study, we asked a large sample of subjects to estimate the sensations evoked by imaginary aerobic and strength training workouts. In the second field study, we collected the corresponding sensation reports from subjects before and after a session of actual exercise (e.g., running, spinning etc.). In addition to self-reported sensations, we also included heart rate (HR) measures in the field study as an objective index of exercise intensity. Our findings suggest that the bodily mapping tool may provide a novel approach for measuring exercise-induced sensations and emotional responses.

Materials and methods

Experiment 1

The first experiment was a proof-of-concept study aimed at assessing the feasibility of mapping bodily sensations resulting from exercise. The Ethics Committees for Human Sciences at the University of Turku, Finland, waived the requirement for formal ethical review. Written informed consent was obtained online, and the study was conducted in accordance with the principles of the Declaration of Helsinki. Instead of measuring sensations immediately after exercise, we employed a between-subjects design in which subjects were asked to imagine undergoing either aerobic exercise or strength training and report the bodily sensations they would expect to feel following the workout.

Methods

Subjects were recruited from Prolific (https://www.prolific.co), and the experiment was conducted on the gorill a.sc online experiment platform (https://gorilla.sc). Participants provided informed consent before completing background information regarding demographics and habitual physical exercise. Data was collected in English. The final sample consisted of 143 females and 162 males with a mean age of 27 years (*SD* = 7.27) and mean BMI of 26.46 (*SD* = 14.65). The median number of years of regular exercise was 4. The median weekly time spent exercising was 3 h for strenuous exercise (e.g. jogging, soccer) and 4 h for light activities (e.g. walking, golf). Participants reported enjoying exercise (median = 8 out of 10), rated their fitness as average (median = 5 out of 10), and their mood as good (median = 7 out of 10). See subject demographics in Table S1.

Bodily sensation mapping

The subjects were asked to imagine that they had completed a vigorous 60-minute exercise session. To standardise imagery and maximise the brevity of responses, half of the subjects were instructed to imagine aerobic exercise (e.g. jogging, cycling, dancing, tennis, aerobics), and half to imagine a strength training workout (e.g. using free weights, kettlebells, resistance bands, gym machines). They were then provided with a list of 52 somatic sensations and asked to evaluate, using a visual analogue scale (VAS; range − 100 to 100), whether the exercise session would increase or decrease the feeling of each sensation. To assess the similarity of the feelings and sensations, hierarchical clustering with the Ward method was performed. After completing the VAS scales, subjects completed the bodily sensation mapping[13,14]. They were shown a blank human body and the name of a single feeling or sensation (e.g. "Energised") and asked to colour all the bodily regions where they would feel that sensation (Fig. S5). The selected sensations and feelings included both widely studied interoceptive states (e.g., pain, fatigue) and subjective bodily experiences that may be relevant to exercise behaviour and motivation (e.g., feeling "fat" or "efficient"). Due to the large number of feeling and sensation tokens, each participant was randomly assigned to report on half (26 out of 52) of the tokens pertaining bodily sensations to reduce the cognitive load. Participants completed the mapping task one sensation at a time and had the option to correct their colouring before moving to the next sensation. The total number of coloured pixels was used as a proxy for the intensity of each sensation. As participants were instructed to indicate the location of sensations, pixel coverage provides an indirect approximation of the sensation's intensity. Topographical maps for each token were averaged, and the mean maps were subjected to mass univariate t tests against zero to reveal regions where each experience increased statistically significantly. False Discovery Rate (FDR) correction[43] was applied to control for multiple comparisons. All data processing and statistical analyses were conducted using MATLAB R2022a (The MathWorks, Inc., Natick, Massachusetts, United States) and R statistical software version 4.22 (The R foundation, Vienna, Austria), including the packages corrplot, superheat, GGally, ggplot2, ggridges, forcats, MASS, factoextra, ggpubr, cluster, coefplot, psych, Rtsne, ggrepel, lessR, readxl, viridis, rempsyc.

Results

Figure 1 shows the mean distribution of the rated sensations. No statistically significant differences were found between the mean intensity of the feelings and sensations for imagined aerobic and strength training conditions, and the feeling-wise ratings across the conditions were almost perfectly correlated (r=.99, p<.001); therefore, these data were subsequently analysed together. Imagined exercise particularly increased the sensations of sweatiness, strength, activeness, efficiency and warmth, and decreased the sensations such as fatness, weakness, numbness, stabbing and fainting. All differences from zero were statistically significant (ts > 1.90, ps < 0.05) except for cool, tingling, and tight. See Table S2 for full statistics.

Cluster analysis (hierarchical clustering using the Ward method) revealed a clear six-cluster structure for the similarity of the feelings and sensations (Fig. 2). Torso-focused sensations (aroused, fat, straight-backed, and stabbing) formed one cluster, while low-intensity feelings (calm, faint, peaceful, cool) were grouped into another. Cardiovascular sensations (e.g. sweaty, breathless, bursting, pulsating) formed one cluster, and Exhaustion-related sensations (e.g., uncomfortable, exhausted, chafed) were grouped together. Limb-centred sensations (e.g. dexterous, shaky, trembling) formed another cluster, and the remaining sensations formed the final, largest Whole-body cluster (e.g., swollen, bruised, jiggly, supple).

We next analysed the bodily sensation maps for imagined exercise-induced sensations (Fig. 3). Imagined physical exercise was associated with consistent experience of bodily sensations across subjects, with the intensity and bodily topography of these sensations varying significantly between different sensations. Some sensations, such as warmness, sweatiness, and exhaustion, were felt throughout the whole body, while others, like strength, agility, and flexibility, were localised in the limbs. Some sensations, such as breathlessness and pulsation, were primarily felt in the upper torso, whereas others, like discomfort, sluggishness, and numbness, were experienced only rarely. Finally, calmness and peacefulness were predominantly experienced in the head area, likely reflecting the psychological rather than embodied nature of these experiences.

To further visualise the embodied nature of the imagined exercise-evoked feelings, we computed the mean number of pixels coloured in head and body regions for each sensation[44]. We considered colouring on the body region to imply the bodily component of the sensations, and colouring on the head to reflect mentation, here referred as the mental component. This dimensional reduction approach is based on our previous work on 100 core feelings, which showed that the mental phenomenological experience of subjective states or physiological

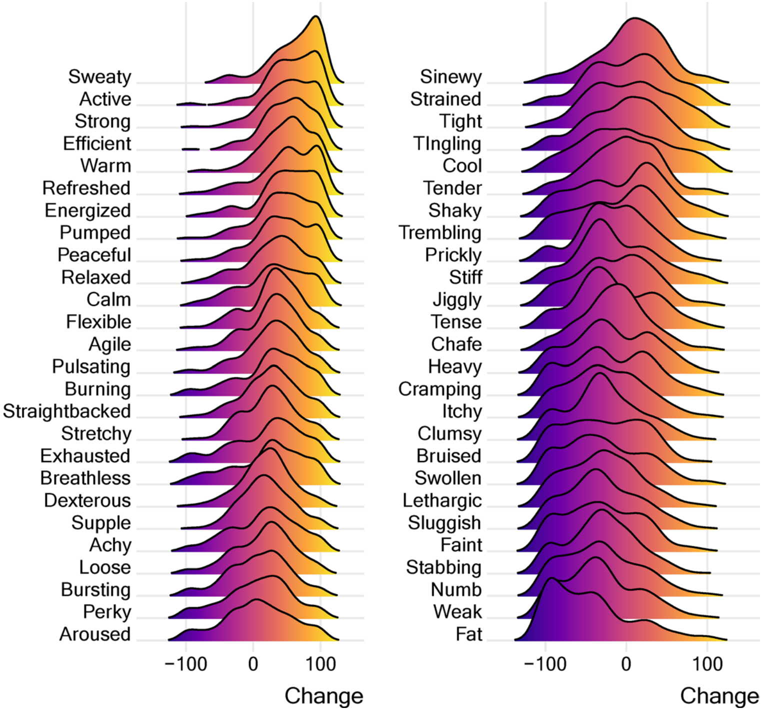

Fig. 1. Mean distributions of the intensity of pooled sensations from imagined aerobic and strength training conditions in descending order. All differences from zero are statistically significant (*ts* > 1.90, *ps* < 0.05) except for shaky, cool, tingling and tight.

changes is associated with sensations in the head area[14]. However, this classification reflects the location of reported experience rather than the physiological origin of the sensation. For instance, while sweating is an autonomic response, it was classified under the mental component in our analysis because participants commonly mapped it to the head area, likely reflecting subjective awareness (e.g., sweating on the forehead) rather than theoretical understanding of its physiological origin. Our analysis revealed clear gradients in both the mental and bodily components of the sensations (Fig. 4). Sensations of warmth, activeness, sweatiness, and energy were most prominently felt in the body, whereas faintness, clumsiness, itchiness, and chafedness lacked a strong bodily component. Peacefulness, calmness, sweatiness, and relaxation were primarily experienced in the mind, while shakiness, stabbing, cramping, and bruised were less associated with a mental component.

Experiment 2

Experiment 1 suggested that subjects estimate exercise to induce a wide variety of bodily sensations, and that these sensations are evaluated consistently across individuals. In the second field experiment, we mapped exercise-induced emotional and bodily feelings in a real-world, self-selected exercise environment (naturalistic training setting), where participants engaged in their usual sports or workouts rather than a standardised laboratory protocol. The Ethics Committees for Human Sciences at the University of Turku, Finland, waived the requirement for formal ethical review. Written informed consent was obtained online, and the study was conducted in accordance with the principles of the Declaration of Helsinki. Subjects were recruited from various sport clubs, training groups, and workout/dance halls. We decided to use self-selected voluntary sports as the experimental model, as it more closely represents natural recreational exercise compared to laboratory-based or experimenter-led exercise sessions. To minimise interference with the exercise classes, we trimmed down the adjective list for the VAS and bodily mapping task from Experiment 1, allowing the experiment to be completed in approximately 10 min. Data was collected in Finnish.

Methods

A research assistant contacted the subjects upon arrival at the sports facility and enquired about their willingness to participate. Upon enrolling, subjects provided informed consent and were given instructions along with a private code to log on to the experimental platform (https://gorilla.sc). Subjects were encouraged to complete the experiment on their own device; iPads were also available for those who preferred them. The sampling resulted in 133 young adult volunteers (29 males, 105 females) with a mean BMI of 23.01 (*SD* 3.32). Subjects reported exercising 4.59 h/week (*SD* = 1.68) and assessed their cardiorespiratory fitness on a 1 (extremely poor) to 7 (extremely good) scale as above average (*M* = 4.74, *SD* = 0.92). See Subject Demographics in Table S3. Before the exercise, subjects provided background information and reported their current feelings using 12 adjectives describing common emotional and somatic states. Subsequently they completed the bodily mapping task for six researcher-selected bodily sensations commonly related to exercise, which also had resulted in distinguishable

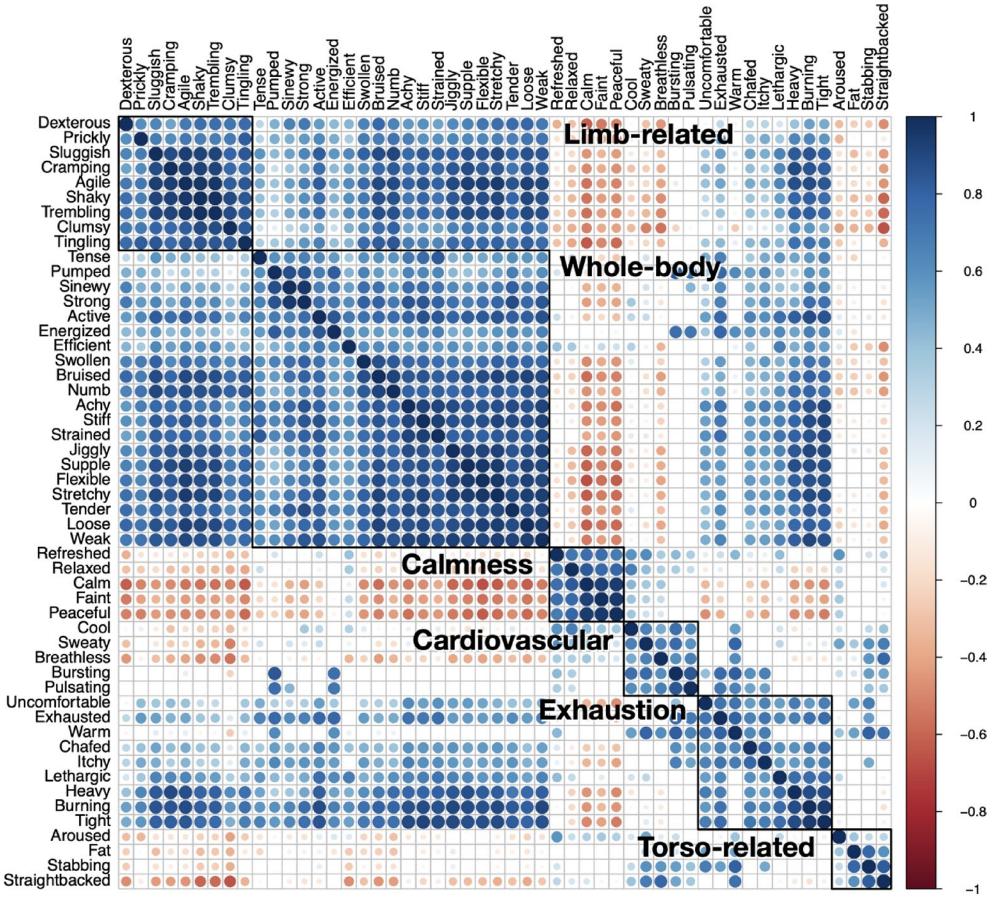

Fig. 2. Similarity structure (Pearson correlation) of the bodily sensations. Colouring and dot size indicate the strength of the correlation and the black outlines the hierarchical 6-cluster structure. Only statistically significant ($p<.001$) correlations are shown.

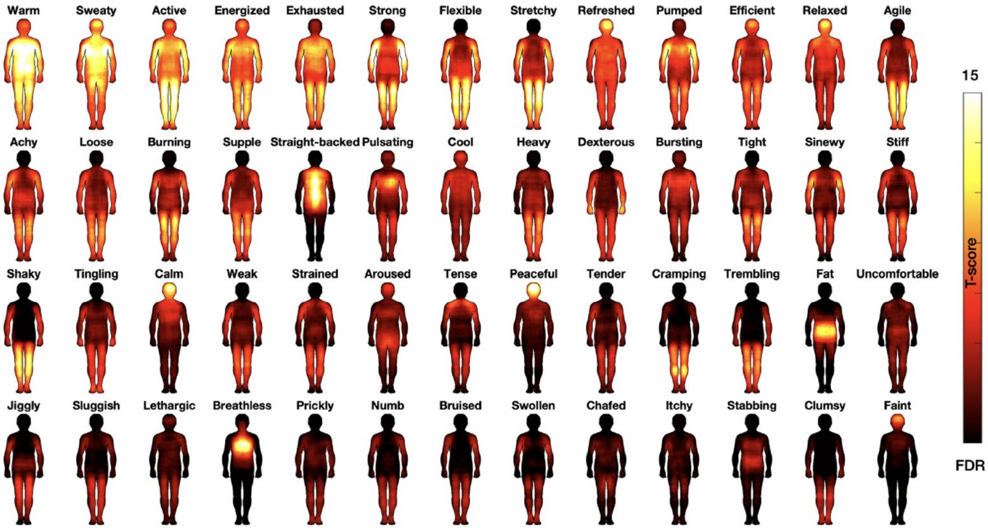

Fig. 3. Bodily sensation maps for imagined physical exercise, with data pooled across imagined aerobic and strength training conditions. Pixel intensities show t-values. The data are arranged per total coloured bodily area and thresholded at $p<.01$ FDR corrected.

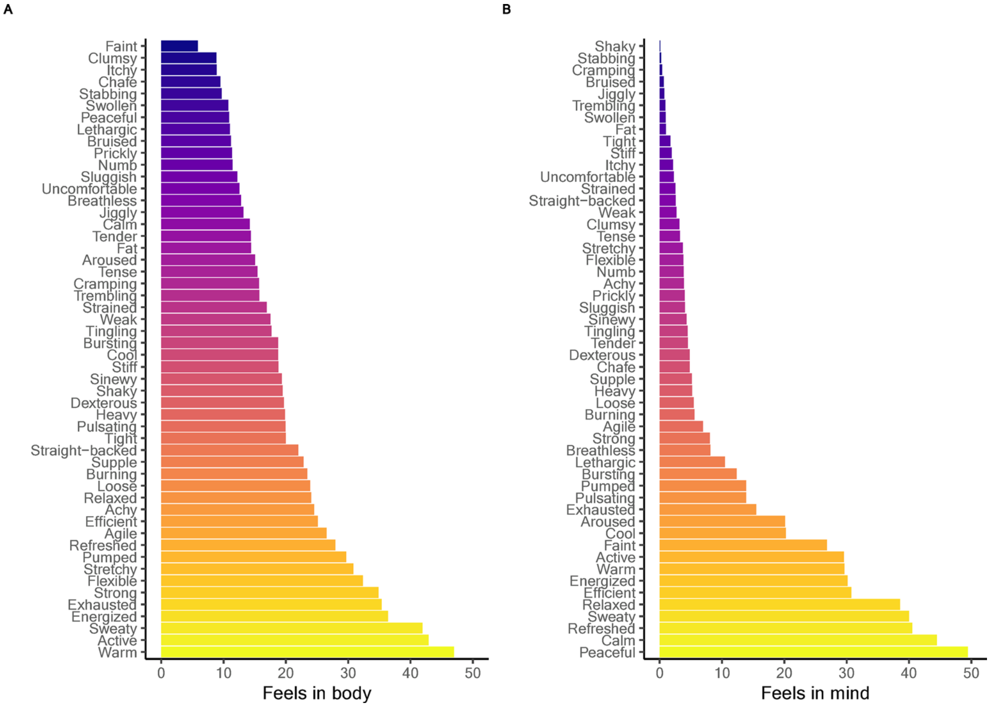

Fig. 4. Bodily (**A**) and mental (**B**) components of the imagined exercise-induced sensations. X axis shows the mean intensity for the VAS scores. Note that the data are ordered separately for the left and right panels.

maps in Experiment 1 (Active, Uncomfortable, Painful, Exhausted, Relaxed, and Supple). Unlike Experiment 1, subjects were now asked to paint the body where they currently experienced each sensation. The subjects then completed their exercise, after which they immediately re-evaluated their subjective state using the 12 adjectives and repeated the bodily mapping task for their current sensations. Subjects were also asked to evaluate the strenuousness of the exercise session using the Borg Rating of Perceived Exertion (RPE) scale ranging from 6 (no exertion) to 20 (maximal exertion)[45], and to rate how much they enjoyed the exercise session on a 1–7 scale (1 = extremely little; 7 = enormously). Subjects wearing personal heart rate monitors were asked to enter their mean heart rate during the exercise session into the electronic form; these data were obtained from 44 subjects.

Subjective sensations in the pre- and post-exercise measurements were compared using paired t-test. The bodily maps were generated as previously, but to assess exercise-induced changes in bodily sensations, the post-test maps were compared with the pre-test maps using repeated measures t-tests. The total number of coloured pixels was used as a proxy for the intensity of each sensation, providing an indirect estimate based on the marked area. To assess the relationship between bodily sensation maps and self-reported exertion and fitness level, we computed the total number of pixels coloured for each sensation after exercise to indicate the net bodily sensation; these values were subsequently correlated with the RPE scores, mean heart rates during the exercise, self-assessed fitness level, and weekly hours of exercise. All data processing and analyses were performed using the same software as described in Experiment 1.

Results

Most subjects performed aerobic exercise either in a group ($n = 93$) or on their own (6). Others participated in group body maintenance activities ($n = 19$), strength training in a group ($n = 5$) or alone ($n = 10$). No subgroup analyses were conducted, as the number of participants performing strength training or body maintenance activities was too small for meaningful comparisons. The mean RPE was 14.02 ($SD = 2.9$) and heart rate 132.6 beats per minute ($SD = 22.41$, $n = 44$), indicating a moderate-intensity exercise. The modal length of the exercise session was 57 min. On a scale of 1–7, participants reported liking the exercise “very much” (mean 5.62; $SD = 0.94$). In general, exercise increased the experience of positive feelings and decreased experience of negative feelings. Statistically significant increases were observed in the experience of healthiness, happiness, pride, perkiness, energy, and attractiveness, while significant decreases were observed in the experience of exhaustion, stress, lethargy, anxiety, depression, and embarrassment ($ts > 1.92$, $ps < 0.05$; Fig. 5 and TableS4).

The bodily sensation maps revealed distinctive topographical experience patterns for different sensations (Fig. 6). Exercise increased the experience of activeness and suppleness in the chest and back areas, and led to increased experience of exhaustion in feet and relaxation in the head. Conversely, the experience of exhaustion decreased in the head and shoulder area, while uncomfortable and painful sensations decreased in the upper torso region.

Next, we tested whether the spatial intensity of bodily sensations (as indexed with total percentage of pixels coloured) after exercise was associated with physiological (heart rate) and subjective estimates of perceived exertion (RPE). Bodily sensation of exhaustion showed significant correlations with both measures of exercise

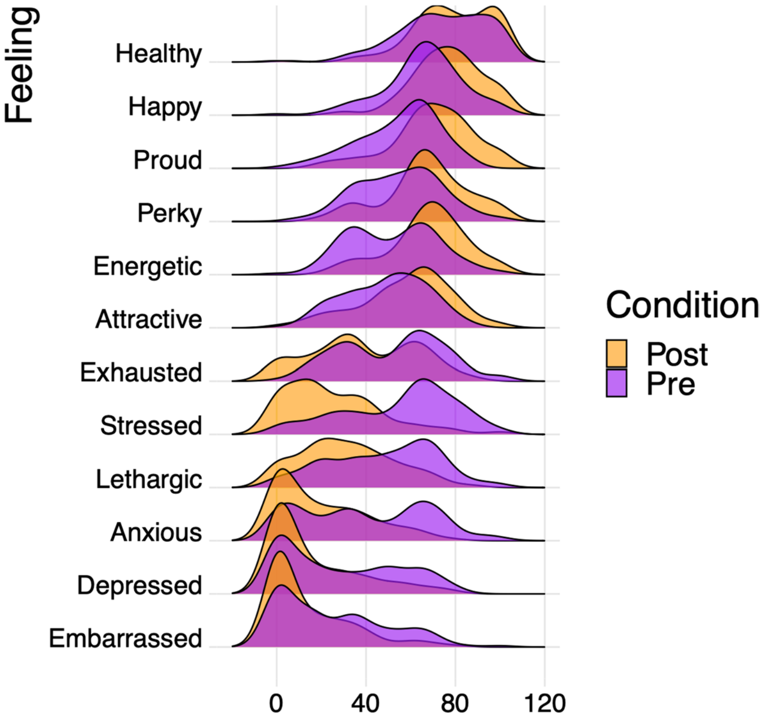

Fig. 5. Distributions of emotional and somatic feelings before and after the workout. Differences in all sensations between pre and post measurements are statistically significant at $p < .01$.

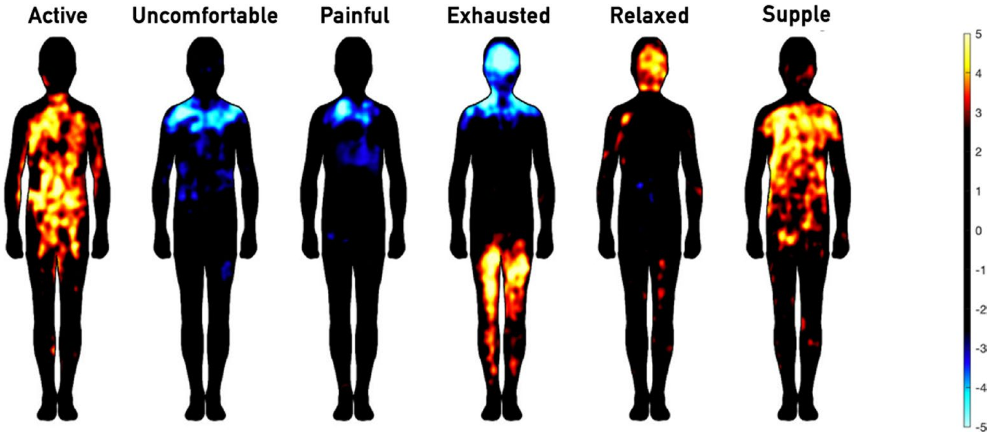

Fig. 6. Bodily maps of exercise-induced sensations. The maps show regions where experience of each sensation increased (hot colours) or decreased (cool colours) in comparison with the baseline state. Pixel intensities show t-values. The data are thresholded at $p < .05$ FDR corrected.

intensity (RPE: $r = .33$, $p < .001$; heart rate: $r = .41$, $p = .002$), indicating that more intensive exercise was linked with a stronger experience of exhaustion in the body (Fig. 7). No other significant associations were found between bodily sensations and indices of exercise intensity. Additionally, self-reported physical fitness was negatively associated with the bodily experience of pain ($r = -.25$, $p = .003$) and uncomfortable sensations ($r = -.30$, $p < .001$). No significant correlations were found between weekly hours of exercise and bodily sensations.

Discussion

Our main finding was that physical exercise induces a wide array of somatovisceral sensations whose topographies are consistent across individuals. Exercise-induced sensations were predominantly positive, whereas the experience of negative sensations decreased following exercise. These sensations were associated with generally distinct bodily topographies, ranging from whole-body experiences (such as feeling warm or sweaty) to region-specific feelings (like feeling agile, or shaky). Some sensations, such as calmness or faintness, were localised mainly to the head region, likely reflecting their predominantly mental nature. The field experiment confirmed

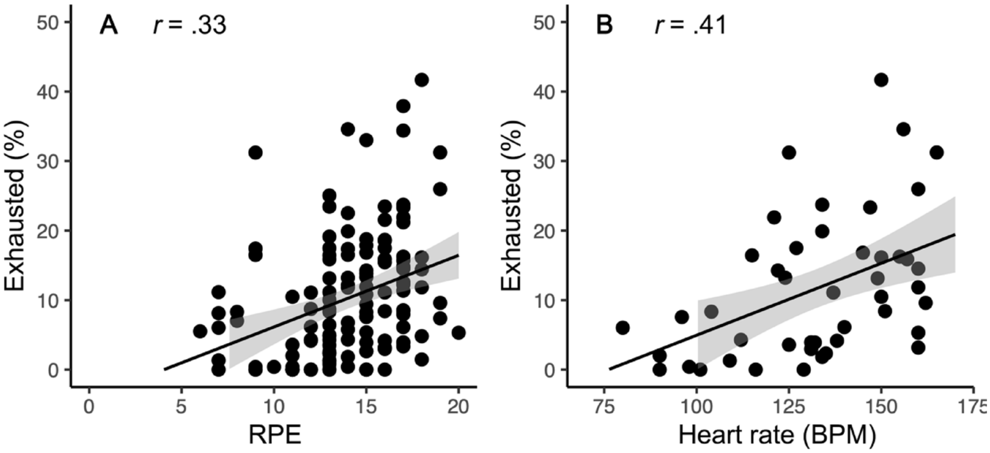

Fig. 7. Association between bodily exhaustion (as indicated by the body sensation map) and exhaustion as indexed by self-report based on the Borg' rating of perceived exertion (RPE) scale (**A**) and mean heart rate (beats per minute; BPM) during exercise (**B**).

that bodily sensations of activity and exhaustion intensified following exercise in topographically specific manner, and that the experience of exhaustion in the body mapping was linearly associated with physiological (heart rate during exercise) and subjective (RPE) indices of exertion. Altogether these results demonstrate that different exercise-induced sensations have generally distinct bodily topographies and suggest that physiological changes contribute to these sensations.

Bodily sensations and physical exercise

Imagined exercise was primarily associated with an increase in positively valenced sensations (e.g. active, strong, energised) and a decrease in negatively valanced sensations (weakness, sluggishness, numbness). This aligns with a substantial body of research on the relationship between moderate-intensity aerobic exercise and positive mood[8,46,47], which may influence exercise performance, continuation, and future engagement in exercise. The bodily sensations reported using visual analogue scales formed six distinct clusters ranging from whole-body experiences to sensations localised in the limbs, torso, and cardiovascular system. Calmness related and exhaustion/arousal related sensations were also grouped into distinct clusters. The bodily sensation mapping revealed distinguishable topographies for imagined exercise-induced sensations, ranging from whole-body experience of warmth, sweating, and activeness to regionally specific sensations of strength, agility and flexibility. For example, strength was experienced only in the limbs, breathlessness in the chest area and so forth. These findings suggest that people can consistently access the nonverbal interoceptive sensations triggered by exercise[48]. Given that emotions and sensations evoked by exercise are important determinants of sports performance[3,38,49,50] and exercise engagement[21,22,24,25,51], the bodily mapping approach could reveal whether sensations in specific bodily regions (such as aching in the limbs or exhaustion in the chest area) are associated with exercise motivation and mood changes following exercise. This hypothesis aligns with the recently introduced Affective-Reflective Theory (ART) of physical inactivity and exercise, which posits that automatic affective responses to exercise stimuli (type 1 process) can drive immediate behaviour particularly when self-control resources are low, while reflective evaluations (type 2 process) support deliberate action plans when self-control is available[52]. By integrating bodily sensation mapping with the ART framework, interventions could target negative sensations, reframing them as positive to foster reinforcement, enhance exercise motivation, and support adherence to regular exercise routines.

Since Experiment 1 was based on self-reports of hypothetical somatic consequences of exercise, we cannot conclude whether these sensations reflect actual experiences induced by exercise. However, field experiment 2 confirmed that actual physical exercise evokes distinct topographies of different self-reported experience of sensations and feelings. Following exercise, compared to baseline, the sensations of activeness and suppleness increased in the torso area, while relaxation was more prominently felt in the head area. Sensations of pain and discomfort decreased in shoulder and back areas, supporting the role of exercise in musculoskeletal pain management[53]. This finding also aligns with the phenomenon of exercise-induced hypoalgesia (EIH), where a single bout of physical exercise can lead to a reduction in pain perception during exercise and for some time afterward in healthy, pain-free adults[54]. Interestingly, the experience of exhaustion increased in the lower limbs but decreased in the head area following exercise, likely reflecting changes in both physical and mental components of exertion. One possible explanation is a reallocation of attentional focus, from general mental fatigue to more localised muscular sensations. Alternatively, this pattern may reflect a decoupling of physical and mental fatigue, where increased pleasurable physical exhaustion alleviates the experience of mental fatigue. Central fatigue theory suggests that interoceptive feedback from physical exertion is processed in brain regions responsible for sensory integration, emotional evaluation, and decision-making. This integration can modulate mental perceptions of fatigue, potentially contributing to the decoupling effect[55]. Consistent with this, exercise is often described to increase feelings of energy and revitalisation[56–59].

Bodily sensation of exhaustion was also directly linked with subjective (RPE) and physiological (heart rate) indicators of exercise load. Given the well-established regulatory role of exercise intensity on emotional responses of exercise[8,46], it is not surprising that exercise intensity modulates also the overall bodily experience of exhaustion. Association between self-reported bodily sensations and increased heart rate suggests that the self-reported bodily sensations may have physiological basis[13], as has previously shown for RPE[60,61]. However, other sensations such as pain, activeness, and relaxation did not show significant correlations with HR, suggesting that different bodily sensations may be influenced by distinct physiological systems and cognitive interpretations rather than a uniform interoceptive process. HR primarily reflects cardiovascular effort, whereas sensations such as pain, activeness, and relaxation may involve additional factors such as muscle fatigue, thermoregulatory responses, and cognitive expectations. Moreover, in our field experiment, most participants engaged in aerobic activities, while a smaller subset performed strength training. While our findings pertain to generalisable exercise-induced sensations, different exercise modalities may nevertheless elicit distinct bodily experiences due to variations in biomechanical and physiological demands. Given that aerobic exercise typically involves sustained cardiovascular exertion and strength training emphasises localised muscular load, these modalities may differentially activate the physiological systems underlying interoceptive responses. Future studies with larger and more balanced samples could systematically compare these exercise types to determine whether variations in exertion patterns, muscle recruitment, and energy metabolism influence the distribution and intensity of bodily sensations. Furthermore, the complexity of interoceptive processing warrants the incorporation of a broader array of physical markers such as body temperature, respiration, metabolic parameters, and muscle power to provide a more comprehensive understanding of the interplay between interoception and bodily sensations during exercise. Also the total-body positron emission tomography perfusion imaging might help to reveal the integration of the central and peripheral emotion circuits[62].

Moreover, we found that higher self-assessed fitness level was associated with greater reductions of bodily sensations of pain and discomfort after exercise. While participants' fitness was not objectively measured in the present study, previous research has shown that higher individual fitness level is associated with both greater acute EIH responses[63] and increased endogenous opioid activity following exercise[64], which may be one of the mechanisms modulating exercise-induced analgesia[65]. These findings suggest the role of fitness level in shaping bodily experiences of exercise, potentially via physiological, cognitive, and emotional adaptation. In this context, bodily sensation mapping could serve as a useful tool in monitoring and personalising exercise programs based on individual differences in perceived exertion and recovery.

The field experiment also revealed that while exercise caused exhaustion, it simultaneously increased the experience of positive emotions (feeling healthy, happy, proud, perky, energetic, and attractive) and decreased the experience of negative emotions (feeling stressed, lethargic, anxious, depressed, and embarrassed). This is consistent with the overall pattern of results in Experiment 1, as well as with the literature on the mood-lifting capacity of exercise[8,46]. Interestingly, although embarrassment related to one's body may lower exercise motivation[66], our study shows that engaging in voluntary self-selected physical exercise is an effective way to tackle embarrassment and boost feelings of pride and attractiveness.

All in all, our data show that the bodily sensation mapping tool is sensitive to detecting exercise-induced regional changes in self-reported bodily sensations, providing a detailed visualisation of how we perceive and experience our physical activities. Therefore, it could be a valuable tool for enhancing bodily knowledge, which emphasises understanding and awareness of one's bodily states, movements, and sensations by integrating both the physiological and experiential aspects of the body[67]. Learning to adapt to uncomfortable bodily sensations is crucial not only for elite athletes but also for novice exercisers adopting new training routines[37]. Given that subjective evaluations of exercise-induced sensations vary across individuals – where some find sensations like pain, fatigue, and arousal invaluable to the 'hurt so good' effect of exercise[2,33], others may perceive the associated physical strain as unpleasant[59] – body sensation mapping can bridge the gap between subjective experiences and physiological states, offering insights into how our bodies respond and adapt to physical challenges, and helping to communicate and re-interpret such sensations. From a practical standpoint, bodily sensation mapping could also be useful in personal training and physiotherapy for tracking regional changes in muscle strain or exhaustion, monitoring and improving performance and recovery, and designing more pleasant and tolerable exercise programs to support sustainable exercise routines. As mobile applications have shown promise in automatic emotion classification[68], future work could focus on developing digital applications that integrate bodily sensation data with data from wearable sensors, enabling new approaches for remote real-time sensation tracking, early detection of potential issues, and personalised feedback in exercise settings. Moreover, as our method derives intensity from the total number of coloured pixels, reflecting the spatial intensity of sensations, it does not allow participants to explicitly indicate changes in intensity within a fixed bodily region. Future adaptations of the tool could incorporate an explicit intensity-modification feature to capture localised variations in sensation strength.

Limitations

A limitation of Study 1 is that imagined exercise relies on participants' subjective representations rather than real-time physiological states, meaning that expectancies and general knowledge of exercise effects may have influenced responses. The field experiment was conducted in naturalistic settings and subjects were recruited from exercise studios, dance classes and so forth. This led to variation in the types of exercise the subjects did, yet it ensured that all subjects were exercising in their preferred way, which has been associated with more positive emotional experience[69]. Emotional responses during and after exercise can be markedly different[46]. Our findings only apply to the changes (pre-post) in bodily experiences induced by the exercise session. Heart rate measurements were only recorded from a subset of the subjects using consumer-level heart rate monitors, yet they were robustly associated with exhaustion measures derived from the body maps. We only measured a limited number of bodily sensations in the field experiment to minimise subject discomfort. Future studies using standardised exercise protocol should be conducted using the full array of sensations in Experiment 1. Participants' age was not collected in the field experiment. Since bodily sensations can weaken with age[15], future studies should consider the effects of age on bodily sensation mapping in exercise settings. Our field study involved moderately fit, normal weight participants with regular exercise background. Given that obesity[70,71], poor cardiorespiratory fitness[72], and low level of regular exercise[73] are all associated with more negative emotional responses to exercise, our findings cannot directly be extended to these population groups. Similarly, also gender imbalance may lower the generalisability of the findings. In addition, the bodily sensation mapping tool used a single generic body shape without separate front and back views. Since the goal was to capture subjectively felt locations rather than anatomical precision, this approach offered a practical and reliable solution for large-scale, self-administered studies, while maintaining consistency with prior validated research[13–15,44]. While previous studies have demonstrated the consistency of bodily maps across individuals[13–15,44], future studies could measure a test-retest reliability of the sensation maps. Finally, as the study was based on self-reports, we cannot determine whether the bodily sensation patterns are directly related to changes in the activity of specific physiological systems. However, the observed association between bodily sensation of exhaustion and heart rate indicates that at least some of the subjective sensation patterns are linked to the underlying physiological processes induced by exercise. Future studies using, for example, total-body positron emission tomography perfusion measurements[62] could resolve this issue.

Conclusions

We conclude that bodily sensations are a core component of the exercise-driven emotional experience. Bodily sensation mapping provides a novel tool for understanding the integration between bodily signals and emotional processing in physical exercise. Unlike conventional self-report methods, which rely on verbal descriptors or predefined body regions, this complementary approach allows for a spatially detailed and intuitive assessment of bodily sensations, enabling precise localisation and distribution analysis. Moreover, it offers a new method for quantifying perceived exercise load and concomitant feelings, and may prove valuable in evaluating the psychological and somatic effects of exercising.

Data availability

The datasets generated and analysed during the current study are not publicly available due to Finnish legislation, which requires explicit consent from participants for data sharing. Contact corresponding author (tiina.saanijoki@utu.fi) for more information.

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Author contributions

TS and LN designed the study; TS performed research; LN analysed data; TS and LN wrote the paper. Both authors have approved the final version.

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Declarations

Competing interests

The authors declare no competing interests.

Ethics approval

The Ethics Committees for Human Sciences at the University of Turku, Finland waived the study from formal ethical review.

Additional information

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