Data in Brief 42 (2022) 108257

Contents lists available at ScienceDirect

Data in Brief

journal homepage: www.elsevier.com/locate/dib

Data Article

Interoception during aging: Functional neuroimaging data from a heartbeat detection task

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A R T I C L E I N F O

Article history:
Received 27 October 2021
Revised 29 April 2022
Accepted 4 May 2022
Available online 11 May 2022

Dataset link: Interoception during aging: The heartbeat detection task (Original data)

Keywords:
Interoception
Cardioception
Heartbeat detection task
Aging

A B S T R A C T

Interoception is critically important for allostatic adaptation and emotional regulation, and aberrant interoceptive processing is increasingly recognized to be involved in the pathogenesis of neurological, psychiatric and cardiovascular diseases. Despite the fact that interoceptive abilities decline with age, the corresponding neural correlates and clinical consequences of these age-related changes have yet to be discovered. We present a dataset that contains task-based functional neuroimaging data from 50 adults aged 40–65 years and 12 adults aged 18–25 years who performed an fMRI-based heartbeat-detection task. Of the 62, 38 participants also took part in a rubber hand illusion experiment outside the scanner. While the dataset was mainly created to study age-related changes in interoception, it can also be

DOI of original article: 10.1016/j.cortex.2021.08.009
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https://doi.org/10.1016/j.dib.2022.108257

used in body perception research in general. The provided group data may serve as a reference for clinical studies on interoception involving older adults.

Specifications Table

Subject	Neuroscience: Behavioral
Specific subject area	Brain imaging
Type of data	Image Table
How the data were acquired	MRI was performed with a Siemens MAGNETOM Verio 3T scanner. Functional images were acquired using T2*-gradient echo imaging sequences (TR 2000 ms, TE 21 ms, voxel size 3 × 3 × 3 mm^3, FOV 192 mm). The magnetic field map was obtained with a double-echo gradient field map sequence. A three-dimensional structural image consisted of a sagittal T1-weighted 3D-MPRAGE sequence (TR 1900 msec, TE 2.47 msec, voxel size 1 × 1 × 1 mm^3, FOV 250 mm).
Data format	Raw
Description of data collection	The data were collected from 50 adults aged 40-65 years and 12 adults aged 18-25 years, with no history of cardiovascular events and no severe white matter hyperintensities according to structural MRI. The participants performed the heartbeat detection task in the scanner (task-based fMRI, blocked design). Thirty-eight participants also took part in a rubber hand illusion experiment outside the scanner.
Data source location	Institution: Research Center of Neurology City/Town/Region: Moscow Country: Russia
Data accessibility	Repository name: Openneuro Data identification number: ds003763 Direct URL to data: http://dx.doi.org/10.18112/openneuro.ds003763.v1.0.5
Related research article	O.R. Dobrushina, G.A. Arina, L.A. Dobrynina, E.S. Novikova, M.V. Gubanova, A.V. Belopasova, V.P. Vorobeva, A.D. Suslina, E.V. Pechenkova, O.S. Perepelkina, E.I. Kremneva, M.V. Krotenkova. Sensory integration in interoception: Interplay between top-down and bottom-up processing, Cortex. 144 (2021) 185-197. https://doi.org/10.1016/j.cortex.2021.08.009

Value of the Data

- Most studies on interoception involve young adults. However, interoceptive abilities decline with age, and these changes may be important from a clinical point of view, since interoception plays a major role in allostasis. The current dataset contains neuroimaging and behavioral data on cardioception from participants aged 40–65 years, as well as a reference group of younger adults.
- The provided data can be used by neuroscientists, psychologists and medical researchers studying interoception. The dataset may be included in meta-analyses on the neural basis of cardioception.
- The dataset may serve for the evaluation of interoception across the lifespan, and also as a reference for studies involving clinical groups of older ages. The additional behavioral data from the rubber hand illusion may be used in studies on body schema.

1. Data Description

The dataset structure complies with the Brain Imaging Data Structure (BIDS; https://bids.neuroimaging.io/) standard. The neuroimaging data are organized into 62 folders, one per

Table 1
The ownership questionnaire.

Subscale	Statements
Test	T1. It seemed as if I could feel the touch given to the rubber hand
	T2. It felt as if the rubber hand was my own hand
	T3. It seemed that the touch I felt was caused by the paintbrush touching the rubber hand
Control	C1. It felt as if I had three hands
	C2. It felt as if my hand was turning ‘rubbery’
	C3. It appeared as if the rubber hand was drifting toward my hand

participant. The anatomical (structural) and functional data in compressed NifTI (.nii) format can be found in the “anat” and “func” subfolders of each participant folder. Structural images are anonymized by removing the identifying part of facial tissues. Neuroimaging data are accompanied by “.json” files with detailed description of the acquisition parameters.

Demographic and behavioral data are contained in the “participants.tsv” file. The columns “age” and “sex” correspond to the age and sex; self-reported medical conditions are listed in columns “hypertension” (primary arterial hypertension), “gastrointestinal” (gastrointestinal diseases), “thyroiditis” (autoimmune thyroiditis) and “diabetes” (type 2 diabetes mellitus); columns “BDI”, “SSTAI_S” and “SSTAI_T” correspond to the Beck Depression Inventory, Spielberger State-Trait Anxiety Inventory state and trait anxiety; “IAcc” represents interoceptive accuracy as measured by the heartbeat detection task (for details of the IAcc index calculation, see below). The following columns contain data from the rubber hand illusion experiment: mislocalization, proprioceptive drift (“drift”) and sum of test (“test_own”) and control (“control_own”) questions from the ownership questionnaire scores at different time points (see Table 1). For example, “drift_emerg_15” corresponds to the proprioceptive drift after 15 s from the onset of the emergence phase, “drift_fading_30” corresponds to the proprioceptive drift after 30 s from the onset of the fading phase, and “test_own_15” and “control_own_15” corresponds to the sum of test and control questions from the ownership questionnaire after 15 s from the onset of the emergence phase (the ownership questionnaire was given only during the emergence phase).

2. Experimental Design, Materials and Methods

2.1. Participants

The dataset includes fMRI, structural MRI and behavioral data from 62 adults who participated in a fMRI-based heartbeat detection task as a part of a governmentally funded project on vascular brain injury conducted at the Research Center of Neurology (Moscow). The following inclusion criteria were used: no history of cardiovascular events, such as stroke or myocardial infarction; no severe white matter hyperintensities, according to structural MRI (modified Fazekas score of 2 or less [1]); right-handed.

The dataset incudes 52 subjects aged 40–65 years (6 male; older adults) and 12 subjects aged 18–30 years (6 male; younger adults). Thirty-eight subjects also participated in the dynamic rubber hand illusion experiment in a classroom environment. Part of this dataset including 30 females aged 40–65 years was used in a study evaluating the links between emotional intelligence and age-related white matter changes [2] and also in a study targeted at the description of top-down and bottom-up circuits of sensory integration in interoception [3].

Forty participants from the group of older adults were interviewed about their medical history. According to the interview, 32.5% subjects reported primary hypertension, 17.5% had gastrointestinal diseases, 5% reported autoimmune thyroiditis, and 5% had type 2 diabetes mellitus (controlled by oral hypoglycemic agents).

In the group of older adults (age 40–65 years) the data on the Beck Depression Inventory [4] and The Spielberger State-Trait Anxiety Inventory [5] was available in 46 participants. Thirty seven percent of them had subdepression and 9.3% had clinically significant depression. Trait anxiety was high in 78.2%, moderate in 19.6%, and low in 2.2% of participants; and that state anxiety was high in 41.3%, moderate in 37.0%, and low in 21.7% of participants. In the group of younger adults (age 18–25 years) 16.7% participants had subdepression and 16.7% participants had clinically significant depression. Trait anxiety was high in all the participants; and that state anxiety was high in 91.7%, moderate in 8.3% of participants. The high rate of anxiety corresponds to populational data [6].

2.2. Heartbeat detection task

We used a variant of the heartbeat detection task [7], translated by our group into Russian and adapted for older participants with the aim of keeping instruction as simple as possible. The protocol included heartbeat detection and sound detection conditions, with the latter being used as a control. Each task included an attending phase (20 s), a response phase (6 s), and a rest phase with a fixation cross (6 s). The stimuli sequence consisted of 8 interoceptive and 8 exteroceptive blocks presented in alternating order. The type of condition was indicated on the screen by an ECG/note pictogram, and at the start of the response phase a second pictogram with a finger on a button appeared nearby (see Fig. 1). Onsets times for the conditions can be found in the "sub-*_task-heart_events.tsv" files in the dataset.

During the heartbeat condition, the participants were supposed to focus on the interoceptive sensations originating from the heart. During the attending phase they focused on the sensations without doing any actions, while during the response phase they were supposed to indicate each heartbeat with a button press. The use of artificial techniques such as breath holding or palpation of the pulse on the wrist was prohibited. The participants were instructed not to make guesses, to press the button only when they felt the heartbeat. During the Sound task, "beep" tones were presented at the individual heart rate with a similar random variance (variance was taken from a normal distribution with standard deviation of 50 ms). The participants were instructed to attend to the tones and, during the response phase, to press a button each time they heard a tone. Before the task, the sound level was individually adjusted to the

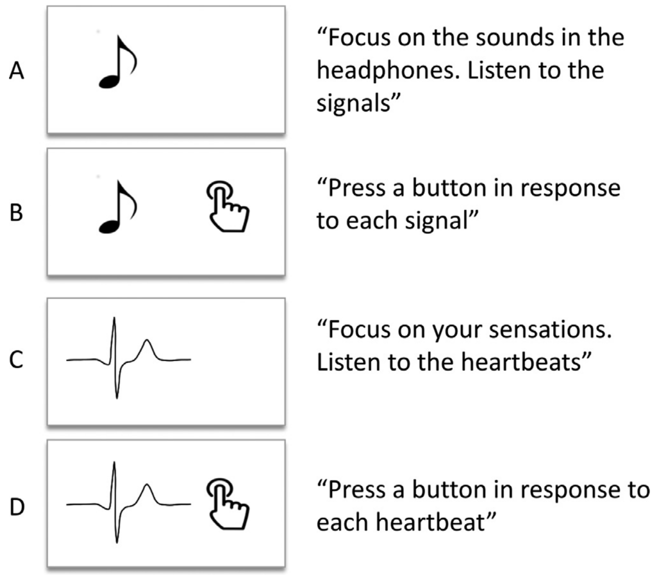

Fig. 1. Experimental stimuli in the heartbeat detection task.

minimum that the participant was able to discriminate from the noise of the scanner. A separate scanning sequence with parameters identical to the one used in the task was performed during the sound adjustment to create noise (data from this sequence were discarded).

Older participants had difficulties understanding the instruction and performing the heartbeat detection task. Thus, the full instruction was given twice: as a presentation outside and inside the scaner. We found a two-step instruction to be the most comprehensible: (1) focus on the sensations/sounds, (2) attend to the heartbeats/signals. The English translation of the instruction is presented in Fig. 1; the original version may be found in a publication in Russian [8].

The images were displayed on the screen during functional neuroimaging to indicate the phases: sound attending (A), sound response (B), heartbeat attending (C), heartbeat response (D). The instructions were given twice: outside the scanner (practice) and in the scanner before the start of the task.

Stimuli presentation and response collection were performed with the use of the Cogent Matlab Toolbox (http://www.vislab.ucl.ac.uk/cogent_2000.php, RRID:SCR_015672) — the code is included in the Openneuro repository. The instruction was presented on the screen, and the participants were able to practice attending to heartbeats/sounds and giving responses with the button press in a brief training sequence. After the instruction, the program waited for a trigger from the scanner to start the stimuli presentation. Synchronization between the computer used for task presentation and the scanner was accomplished through the SyncBox device (NordicNeuroLab). Pulses were recorded with a pulse oximeter by the Siemens Physiological Monitoring Unit, and processed with the use of TAPAS PhysIO Toolbox (https://www.tnu.ethz.ch/en/software/tapas/documentations/physio-toolbox.html). The processing of the pulse data included time synchronization between the pulse recording and the fMRI sequence and peak detection.

IAcc was calculated according to the formula [9]:

$$IAcc = 1/8\sum_{1}^{8}\left(1 - \frac{|Number\,Actual\,Beats - Number\,\mathrm{Res}ponses|}{Number\,Actual\,Beats}\right)$$

The fMRI data can be processed with the use of standard algorithms and software intended for analysis of neuroimaging data, such as Statistical Parametric Mapping (SPM; www.fil.ion.ucl.ac.uk/spm, RRID:SCR_007037), FSL (RRID:SCR_002823), Conn (http://www.nitrc.org/projects/conn, RRID:SCR_009550) or other. In most cases, preprocessing should include slice time correction, calculation of the voxel displacement map, realignment and unwrapping of the functional images, co-registration of the structural and functional images, spatial normalization and smoothing. The dataset can be used both for activation and connectivity analyses, depending on the aim of the study. Interoceptive accuracy as well as other behavioral data can be entered as covariates into the second-level analyses.

2.3. Rubber hand illusion

During the experiment, participants sat still at a table with their right hand hidden in a wooden box (100 cm long, 50 cm wide and 21.4 cm high). The distance from the center of the body to the right hand was 30 cm. A life-sized and gender-matched right hand prosthesis ("rubber hand") was placed medial to the real right hand at a distance of 15 cm. The position of the right hand was similar to that of the rubber one. The left hand was resting on the knees. Before the experiment, subjects were asked to release their right hand from rings and wristbands. The right forearm and the forearm of the rubber hand were covered with black fabric, obscuring them from view. The experiment procedure included two phases: the emergence and fading of the illusion. During the emergence of the illusion, synchronous stimulation to the real and artificial hands was applied with two identical brushes, with a mean frequency of 0.5 Hz; the touches were slightly irregular in duration and interval. Participants were instructed to look at the rubber hand during stimulation. During the fading condition, there was no stimulation: the experimenter removed the rubber hand and the participant could no longer see it, and there was no tactile stimulation.

To evaluate the dynamics of the illusion, we used a behavioral measure of perceived proprioceptive displacement of the real hand under the illusion (proprioceptive drift), and a subjective measure (the ownership questionnaire). Proprioceptive drift was measured as the difference between the initial error in right hand localization (measured before the start of stimulation and labeled “mislocalization”) and the perceived position of the hand after 15, 30, 60, 120, and 240 s from the onset of each condition. The participants were asked to close their eyes, put their left index finger on one of the three fixed points on the top of the box, and to make a pointing movement, stopping the left index finger above the tip of the right middle finger. This procedure was repeated three times in total with the sequence of points randomized, with subsequent averaging. Each measurement started at one of the three points: 5 cm lateral to the participant’s right hand, 30 cm medial or 50 cm medial. The ownership questionnaire [10] was administered at the same timepoints after the proprioceptive drift measurement, but only during the onset phase. The variant of ownership questionnaire was developed and validated by Olga Perepelkina [11]. It consisted of six questions, including three test statements related to the experience of the illusion (test subscale) and three control statements, rated with a 7-point Likert scale (control subscale). The questions were randomized. The sums of the test and control statements were calculated for each time point. The English translation of the ownership questionnaire is presented in Table 1 (the questionnaire was administered in Russian).

Since the rubber hand illusion data includes multiple observations from each subject, mixed linear modelling can be used for the analysis (see [12] for details on mixed models). The dynamics of proprioceptive drift can be modelled with inclusion of time and condition as dependent variables and consideration of the random effects related to individual participants:

$$\mathrm{Proprioceptivedrift} \sim \mathrm{Time} * \mathrm{Condition} + (1|\mathrm{Participant}).$$

The dynamics of ownership questionnaire can be modelled with inclusion of time and subscale (test or control) as dependent variables and consieration of the random effects related to individual participants:

$$\mathrm{Ownershipquestionnaire} \sim \mathrm{Time} * \mathrm{Subscale} + (1|\mathrm{Participant}).$$

Ethics Statements

The study protocol, including inclusion/exclusion criteria, procedures and the analysis plan, was pre-approved by the Ethics Committee and the Institutional Review Board of the Research Center of Neurology (protocol numbers 11-2/19, 4-3/21), and all participants gave written informed consent for participation.

CRediT Author Statement

Olga R. Dobrushina: Conceptualization, formal analysis, project administration, writing – original draft, writing – review & editing, visualization; **Larisa A. Dobrynina:** Conceptualization, project administration; **Galina A. Arina:** Conceptualization, methodology; **Ekaterina V. Pechenkova:** Formal analysis, writing – review & editing, data curation; **Elena I. Kremneva:** Methodology; **Mariia V. Gubanova:** Data curation; **Anastasia V. Belopasova:** Data curation; **Evgenia S. Novikova:** Data curation; **Mariia M. Tsypushtanova:** Data curation; **Angelina G. Makarova:** Data curation; **Viktoriia P. Vorobeva:** Data curation, writing – original draft; **Daria A. Kazantseva:** Data curation; **Vlada V. Aristova:** Data curation; **Anastasia D. Suslina:** Data curation; **Olga S. Perepelkina:** Methodology; **Marina V. Krotenkova:** Conceptualization, project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Interoception during aging: The heartbeat detection task (Original data) (OpenNeuro).

Acknowledgments

The authors thank the administration of Neurology Research Center for assistance with the organization of the study.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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