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# Listening to action-related sentences impairs postural control

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ABSTRACT

According to the mirror neurons data there exist areas in the premotor cortex that are activated both during action perception and action execution. It was hypothesized that posture maintenance would be impaired by simultaneous action perception in concordance with cognitive dissonance theory. A test was conducted during which 23 neurologically normal humans were to maintain their posture erect on the forceplate and to listen to the action-related sentences. Tests of differences and Friedman analysis of variance proved that listening to sentences that describe different actions and movements in the first and the third person impairs postural control in comparison with listening to sentences that describe objects of nature and everyday life.



## 1. Introduction

Recent fruitful and thorough studies upon motor, premotor and parietal areas of primate cortex have revealed complexity of its sensory and motor functions. There were found mirror neurons that discharge when a monkey performs an action or sees another individual perform the same (Gallese et al., 1996). They become active also while a monkey listens to the sounds of the same actions, e.g., breaking a peanut (Kohler et al., 2002). An fMRI study showed that corresponding zones of human brain (Brodmann area 44, Broca's area) respond when an individual listens to the sentences describing actions of others (Aziz-Zadeh et al., 2006).

There were several studies revealing the connection between listening to action-related sentences and execution of actions. It was found that when a subject listens to sentences describing actions executed with the mouth, the hand, and the foot there is activation in the premotor cortex areas that are responsible for execution of actions of the mouth, the hand, and the foot respectively (Tettamanti et al., 2005). In a TMS study, it was demonstrated that amplitude of motor evoked potentials recorded from hand amplitude decrease specifically during listening to hand-action-related sentences and amplitude of motor evoked potentials recorded from foot decrease specifically during listening to foot-action-related sentences (Buccino et al., 2005).

It is well known that the premotor cortex is involved in goal-directed postural control (Bernstein, 1967). Supplementary motor area (human homologue of monkey's F3 area) is sometimes considered to be important for postural control during execution of voluntarily movements and is synaptically linked to Brodmann area 44 and primary motor area (Luppino and Rizzolatti, 2000). Thus, premotor areas are active while an individual performs goal-directed actions, observes such actions, listens to them and are responsible for postural control. Moreover, there are reasons to bear in mind that the insula has mirror neurons (Wicker et al., 2003) and is believed to be critical to postural control (Miyai et al., 1997).

There were conducted many experiments regarding connection between postural control and attention (for a review see (Woollacott and Shumway-Cook, 2002)). But there is a great a difference between attention and memory tests and listening to action-related sentences because the latter activates premotor cortex and therefore can influence postural control directly.

The author has not found any work concerning connection between postural control and listening to action-related sentences. That is why it has been hypothesized that voluntary postural control including biofeedback would deteriorate rather more during a subject's listening to the sentences describing human actions than during a subject's listening to the sentences describing landscapes and everyday life objects. This may happen because of incongruent activations of the same premotor areas. The more extensive and deeper studying of psychophysiological factors of postural control could help neuropsychologists who develop rehabilitation techniques.

## 2. Methods

### 2.1. Subjects

Twenty three healthy subjects with no history of neuromuscular disorders, (8 males, 15 females, age: $21.4 \pm 2$ years, mass:

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65.1 ± 15.3 kg, height: 170.9 ± 6.14 cm, means ± SD), took part in a posturological experiment for the first time. None of them practices sport or physical training regularly. None of them had any orthopedic injury or trauma within 12 months preceding the study. The subjects were naïve to the purpose of the study. All the subjects gave informed consent. Russian was the first language for everyone.

### 2.2. Equipment

A biofeedback two-dimensional biomechanical device Stabilan 01–02 with software StabMed 2.7 (both produced by Ritm, Taganrog, Russia) was applied to register dynamics of center of pressure during the experiment. Stabilan 01–02 consists of a forceplate that the subject stands on and acts as the sensor, a personal computer, and two display screens. The first screen is located 90 cm in front of the eyes of a subject and provides the feedback (Fig. 1). The second screen is used by an experimenter to process the data obtained. The square plate has four load cells located in the corners of it. A subject sees a small red square on the screen which is the projection of his or her center of pressure. Hence, he or she can regulate his or her posture in accordance with tasks. Standing position is the following: heels are situated at two cm from each other at an angle of 30 degrees (Fig. 2).

### 2.3. Procedure

Each subject stood barefoot on the two-dimensional forceplate. In order to familiarize the subjects to the data collection and biofeedback several training video games were used. The training lasted approximately 20 min to adapt the subjects to the apparatus and exclude learning effect that could appear during experimental trials because every participant always acts worse within first minutes. The training period was identical for every person. There were such training games as "Shooting target" (the subjects were asked to stand as straight as they can without deviation from the center of the target), "Balls" (the subjects were asked to put balls into a basket by changing their posture), "Puzzle" (the subjects were asked to make up a puzzle picture by changing their posture), "Tetris" (the subjects were asked to play an inexact analog of Tetris by changing their posture), "Ski slalom" (the subjects were asked to manipulate a skier descending from the hill and avoid small flags by changing their posture).

After adaptation they performed an experimental task in which they tried to maintain their normal erect posture on the immovable forceplate in accordance with a stationary shooting target (Fig. 3) depicted on the screen and listen to the short story simultaneously. Audio-material was played back by the computer. The experimental trial lasted 160 s. The whole procedure lasted approximately 25 min.

**Fig. 1.** Disposition of a participant and equipment. The picture is taken from the software StabMed 2.7.

**Fig. 2.** Disposition of feet on the force plate. The picture is taken from the software StabMed 2.7.

### 2.4. Stimuli

The shooting target was depicted on the computer screen in black and white. It consisted of ten black and white circumferences (Fig. 3).

The purposely composed story consisted of 16 fragments (1 fragment = 1 sentence = 40 syllables = 10 s). Eight of them (the odd ones) described nature, house, streets and other immobile things (object-related sentences). The other eight sentences (the even ones) described movements of people both in the first and in the third person (action-related sentences). All the fragments had the same volume and speed of reading. It was suggested that the fiction story of alternating phrases would attract more attention of participants and be easier to perceive than a set of incoherent or randomly situated sentences would do. The story was in Russian language.

Here is the translated sample of the story used as a stimulus:

*1a. It was a lovely day, the sun was shining brightly, hoarfrost was sparkling on the branches of trees, dazzling snow was lying on the roof of the house next door.*

*1b. I put on my shoes, tied the laces, stood up, took my hat off the shelf, put it on my head, buttoned up my jacket, opened the door and walked out.*

*2a. There was no one in the street, the benches were empty and covered with snow, the sky reflected in the mirror of the frozen puddles.*

*2b. I went to my car, opened the door, sat on the seat, fastened the belt, turned on the ignition, took off the handbrake and carefully drove.*

. . ..

*8a. In these papers there were represented economical tables, graphs, equations, calculations and conclusions.*

*8b. I leaned back in my chair, stretched my feet, switched on the lamp, looked through the stack of the papers and hid them in the case.*

### 2.5. Data collection

Four center of pressure properties were measured. They are following:

1–2. Spread in medial/lateral direction ($x$-direction) and anterior/posterior direction ($y$-direction) – mean-square deviation of center of pressure in corresponding direction relative to the shift:

$$Q_x = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(X_i - \bar{X})^2}\text{, mm}$$

$$Q_y = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(Y_i - \bar{Y})^2}\text{, mm}$$

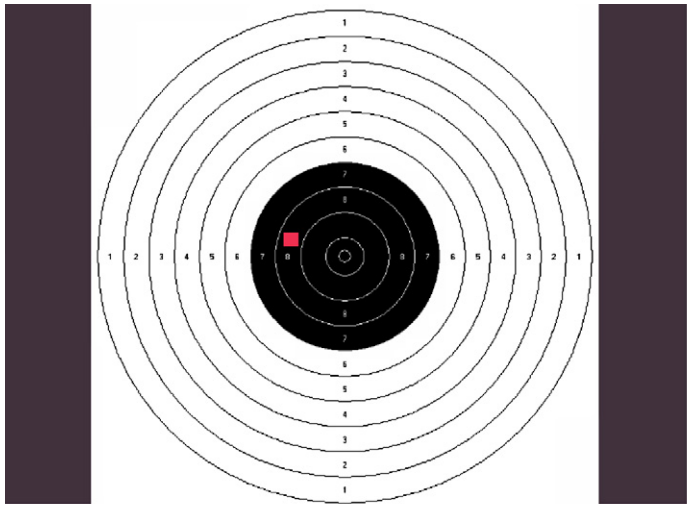

**Fig. 3.** The picture of the shooting target used as a stimulus. The projection of center of pressure is depicted by the red square. The picture is taken from the software StabMed 2.7.

3. Mean spread – mean radius of deviation of center of pressure:

$$R = \frac{1}{N}\sum_{i=1}^{N}\sqrt{(X_i - \bar{X})^2 + (Y_i - \bar{Y})^2}\ , \mathrm{mm}$$

4. Area of confidence ellipse is the main part of statokinesigram area without loops and accidental overshoots. This is the area of functional support of humans.

$S_{\text{ellipse}} = 2\ln\frac{1}{1-\beta}\sqrt{D(X)\cdot D(Y) - \mathrm{Cov}(X,Y)^2}$, mm$^2$; $\beta$ – possibility of hit of a point of the statokinesigram in the ellipse, $D$ – variance of a variable (Stabilan. User manual, 2007).

The data were sampled at 50 Hz. The artifacts were deleted by the built-in tool. All the movements of extremities and head that impaired postural control were considered as artifacts.

### 2.6. Statistical analysis

The statistical analysis was implemented by software STATISTICA 6.0 (StatSoft). A type of sentences was considered as an independent variable (object-related sentences or action-related sentences). Four center of pressure properties mentioned above were measured as dependent variables. The tests of differences (Student's $t$-test if the data were normally distributed, Wilcoxon's test if the data were not normally distributed) were applied to compare means of each center of pressure property during listening to the object-related sentences and to the action-related ones. Gender differences were evaluated by applying Student's $t$-test if the data were normally distributed and Mann–Whitney's $U$-test if the data were not normally distributed. Means of every property were compared regardless of type of stimuli. Then Friedman ANOVA was applied to assess whether there was learning or tiredness effect. This method was chosen as many variables did not have normal distribution. The values of all the center of pressure properties recorded during listening to each of eight object-related sentences were compared with the values recorded during listening to each of eight action-related sentences. For example, if the last measures demonstrate worse values than the first ones regardless of type of stimuli, it means that a subject is tired and his or her posture is impaired by fatigue. On the contrary, if there are better values in the end of the trial regardless of type of stimuli it can be concluded that he or she has trained to maintain his or her posture better, type of stimuli not having influence. The level of significance was set at $p < 0.05$ for all analyses.

## 3. Results

The tests of differences comparing means of each property showed that values of the center of pressure properties are significantly greater when a subject listens to the action-related sentences than in the condition when he or she listens to the object-related sentences (Table 1). No gender differences were found.

To justify that there was no learning or tiredness effect Friedman ANOVA was applied. This analysis revealed that the values of the center of pressure properties are significantly greater when a subject listens to each action-related sentence than in the cases when he or she listens to each object-related sentence (Table 2,

**Table 2**
Friedman ANOVA shows that values of the center of pressure properties are significantly greater when a subject listens to each action-related sentence than in the cases when he or she listens to each object-related sentence.

| Stabilographical property | $\chi^2$ | $p$ |
|---|---|---|
| Spread in medial/lateral direction | 27.06 | 0.028 |
| Spread in anterior/posterior direction | 41.33 | 0.001 |
| Mean spread | 38.58 | 0.001 |
| Area of confidence ellipse | 51.4 | 0.001 |

**Table 1**
The tests of differences between mean stabilographical values when subjects was listening to the objects-related sentences and to the actions-related ones. In all cases $p < 0.001$.

| Stabilographical property | $t$ (Student) | $T$ (Wilcoxon) | Mean (objects) | Mean (actions) |
|---|---|---|---|---|
| Spread in medial/lateral direction, mm | 4.54 | | 1.42 | 1.64 |
| Spread in anterior/posterior direction, mm | | 19 | 2.09 | 2.5 |
| Mean spread, mm | | 5 | 2.25 | 2.63 |
| Area of confidence ellipse, mm$^2$ | | 9 | 43.29 | 60.75 |

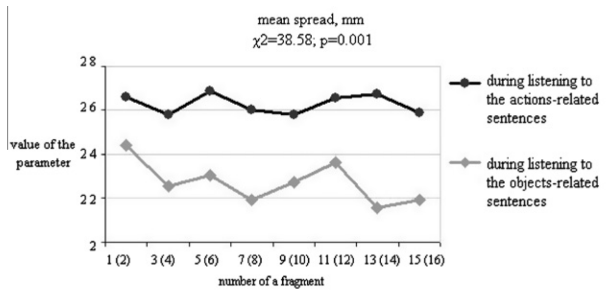


**Fig. 4.** An example of Friedman ANOVA. The mean values of mean spread of center of pressure during listening to all 16 sentences (8 objects-related, 8 actions-related). Every action-related sentence is accompanied by the greater value of the center of pressure property than every object-related sentence is. It means worse postural control.

Fig. 4). In other words, each part in the course of which a subject listens to an action-related sentence provokes a greater value of the center of pressure properties. If the center of pressure properties deteriorated with time regardless of type of stimuli, it would indicate that the subjects became tired. If the center of pressure properties improved with time regardless of type of stimuli it would mean that the subjects learnt to perform better. In both cases it would show that type of stimuli did not play an important role. Therefore there was no learning or tiredness effect in this experiment.

## 4. Discussion

It is obvious that a greater value of the center of pressure properties mentioned above means the worse postural function. The lesser spread (as the mean, as in both directions) and area of confidence ellipse are, the better posture control is.

If the center of pressure properties deteriorated with the course of time regardless of type of stimuli, it would indicate that the subjects became tired. If the center of pressure properties improved with the course of time regardless of type of stimuli it would mean that the subjects learnt to perform better. In both cases it would show that type of stimuli did not play an important role. But in this experiment there was deterioration of postural control function only during listening to the action-related fragments. Therefore there was no learning or tiredness effect in this study that would decrease accuracy of data.

In this study, the analysis of the center of pressure properties showed that postural control is impaired more when humans listen to action-related sentences than when they listen to object-related sentences. This difference may be due to the fact that during action perception there is similar motor cortex activation as if a human being performed the same action (mirror neurons system). Action perception premotor patterns may interfere functioning of postural control patterns since the same groups of neurons should be active to perform two activities. If it did not happen, there would not be any additional motor activation and consequently any difference in postural control in the course of two tasks. These results may be explained by the notion of cognitive dissonance, i.e., simultaneous motor cortex activations induced by postural control tasks and action perception tasks give birth to the impairment of the former.

There exists another explanation for these data. In the parietal cortex there are areas that are responsible for postural control (Perennou et al., 2000). In the intraparietal sulcus there are neurons that describe objects that are located nearby an organ and hence are involved in creating body scheme (Mountcastle et al. 1975). The parietal mirror neurons are situated in inferior parietal lobule in humans (Iacoboni et al., 1999) and in PF of the macaque brain (Fogassi et al., 1998) and may activate postural control zones impairing equilibrium.

Overall, there exist mirror neurons circuits and postural control circuits in the human cortex that are intertwined. Therefore incongruent tasks of action perception and postural balance can impair the latter.

It is worth to mention that the participants did not notice peculiarity of the fiction story. None of them paid attention to the order of the phrases (alternating). However it is necessary to conduct similar experiment in which it would be useful to collect reports of subjects about such audio material, to measure their ability to memorize it. There could be discrepancy in postural control between attentive and not attentive listeners.

Future experiment should strive to define more precisely the connection between postural control and mirror properties of the primate brain. EEG, MEG and TMS studies upon this issue are necessary.

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