# Kinematic predictors for the moving hand illusion

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Academical me

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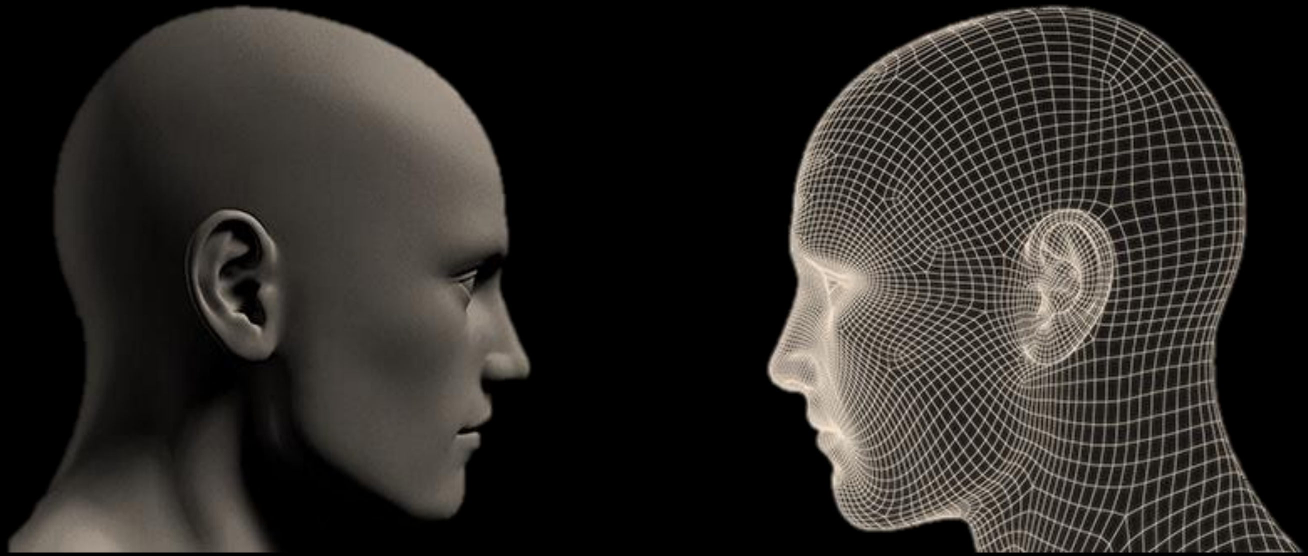
Industrial me

# Body ownership



- Body-ownership refers to the special perceptual status of one's own body, which makes bodily sensations seem unique to oneself, that is, the feeling that "my body" belongs to me [Gallagher, 2000].
- The sense of body ownership is a result of convergent input of several sensory modalities.

# Multisensory integration

- The term multisensory integration refers to the mechanisms by which the brain merges information across sensory modalities to enhance the salience ("perceptual importance") of biologically meaningful events [Stein and Stanford, 2008].
- Principles of multisensory integration: signals from two sensory modalities are much more likely to be integrated if they occur within a specific **time window** and if they originate from the **same region** of the body or external space [Stein and Stanford, 2008].

- Experimental manipulation of different sensory inputs is possible during **perceptual bodily illusions**. These illusions allow studying multisensory mechanisms of body representation.

# Rubber hand illusion (RHI)
[Botvinick & Cohen, 1998]

# Moving rubber hand illusion

- While the rubber hand illusion implies **static** position of a participant's hand, during real everyday manipulations we **move our body a lot**. Therefore kinesthetic information is a very important sensory signal for the body representation.
- In previous studies simple movements were used to create body ownership illusions [Kalckert et al., 2014].

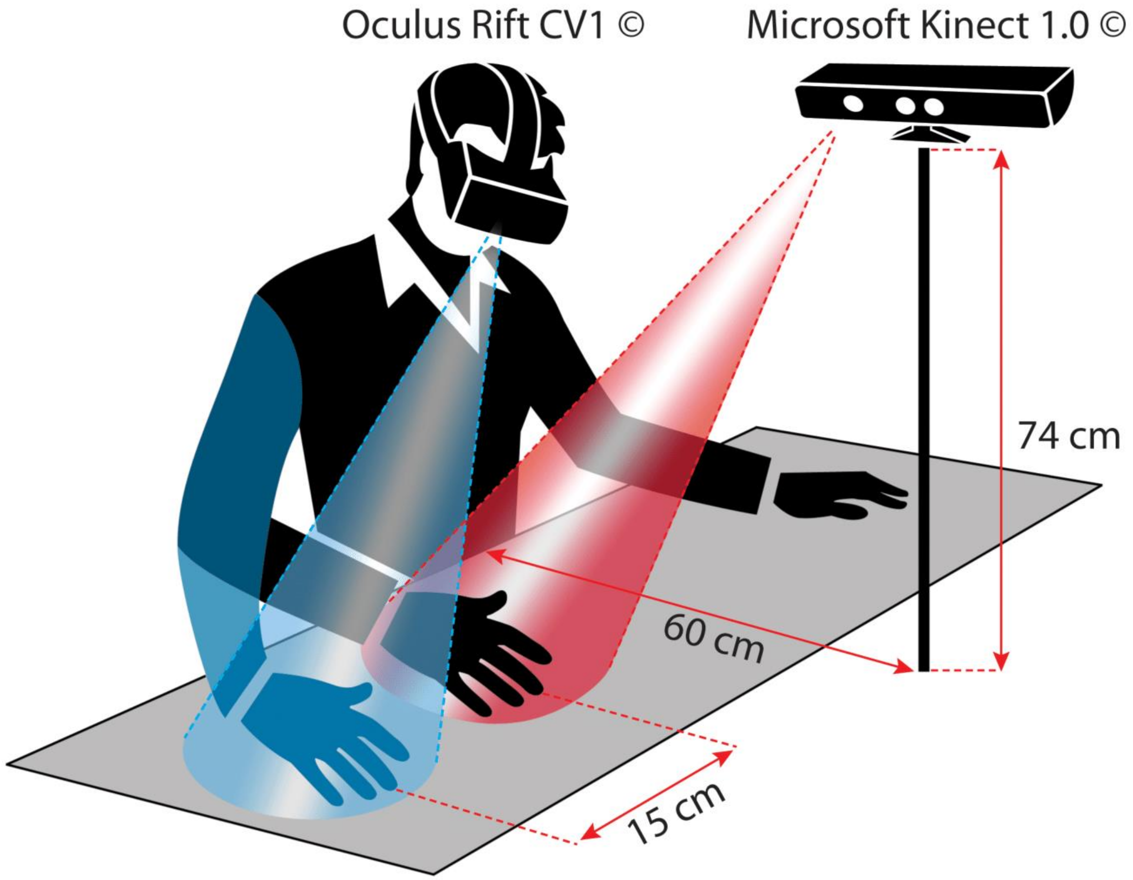
# Research: kinematic predictors for the moving hand illusion

- The aim of this study was to analyze motion characteristics of a moving hand illusion and find out which of these characteristics could predict the strength of the body ownership illusion.

# Subjects

- 33 subjects;
- Age: mean 33.8 ± SD 6.7 years;
- Sex: 52% female, 48% male;
- Right-handed;
- All subjects were relatively naive for VR and with ordinary experience in sports and dances.

# Experimental Setting



General view

First-person perspective

# Measurements of the illusion: ownership

- Ownership questionnaire consisted of four items, two test and two control questions, the latter serving as controls for task suggestibility and expectancy effects.

**Test statements**
T1. It felt as if the virtual limb was the part of my own body.
T2. It seemed as if I felt my hand in the same place as a virtual limb.

**Control statements**
C1. It seemed as if I had no hands, as if they disappeared.
C2. It felt as if I had more than two hands.

# Measurements of the illusion: proprioceptive drift

- Proprioceptive drift – the distance between real and felt positions of the hand.
- The displacement of felt position of hand towards the artificial hand.

# Real movements tracking & recordings

- Kinect + ThreeGear Software [Academic license]


3Gear systems

# Results & Discussion

3Gear systems

```
            T2
             |
  T1         |        T3
   \         |        /
    J7     J10     J13     T4
     \       |      /      /
      J6    J9    J12   J16
T0     \     |    /      /
 \      \    |   /    J15
  J4    J5  J8 J11      /
   \     |   |   |  J14
   J3    |   |   |   /
     \   \   |   /  /
      J2  \  |  /  /
        \  \ | /  /
         \__\|/__/
            J1
             |
            J0


        J0: Root
        J1: Wrist
     J2-T0: Thumb
     J5-T1: Index finger
     J8-T2: Middle finger
    J11-T3: Ring finger
    J14-T4: Pinky finger
```

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             |
  T1         |        T3
   \         |        /
    J7     J10     J13     T4
     \       |      /      /
      J6    J9    J12   J16
T0     \     |    /      /
 \      \    |   /    J15
  J4    J5  J8 J11     /
   \     |   |   |  J14
   J3    |   |   |   /
     \   \   |   /  /
      J2  \  |  /  /
        \  \ | /  /
         \__\|/__/
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3Gear systems

Joint movements were highly correlated:
mean paired Pearson correlation by each coordinate was 0.91

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   \     |   |   |  J14
   J3    |   |   |   /
     \   \   |   /  /
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        \  \ | /  /
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3Gear systems

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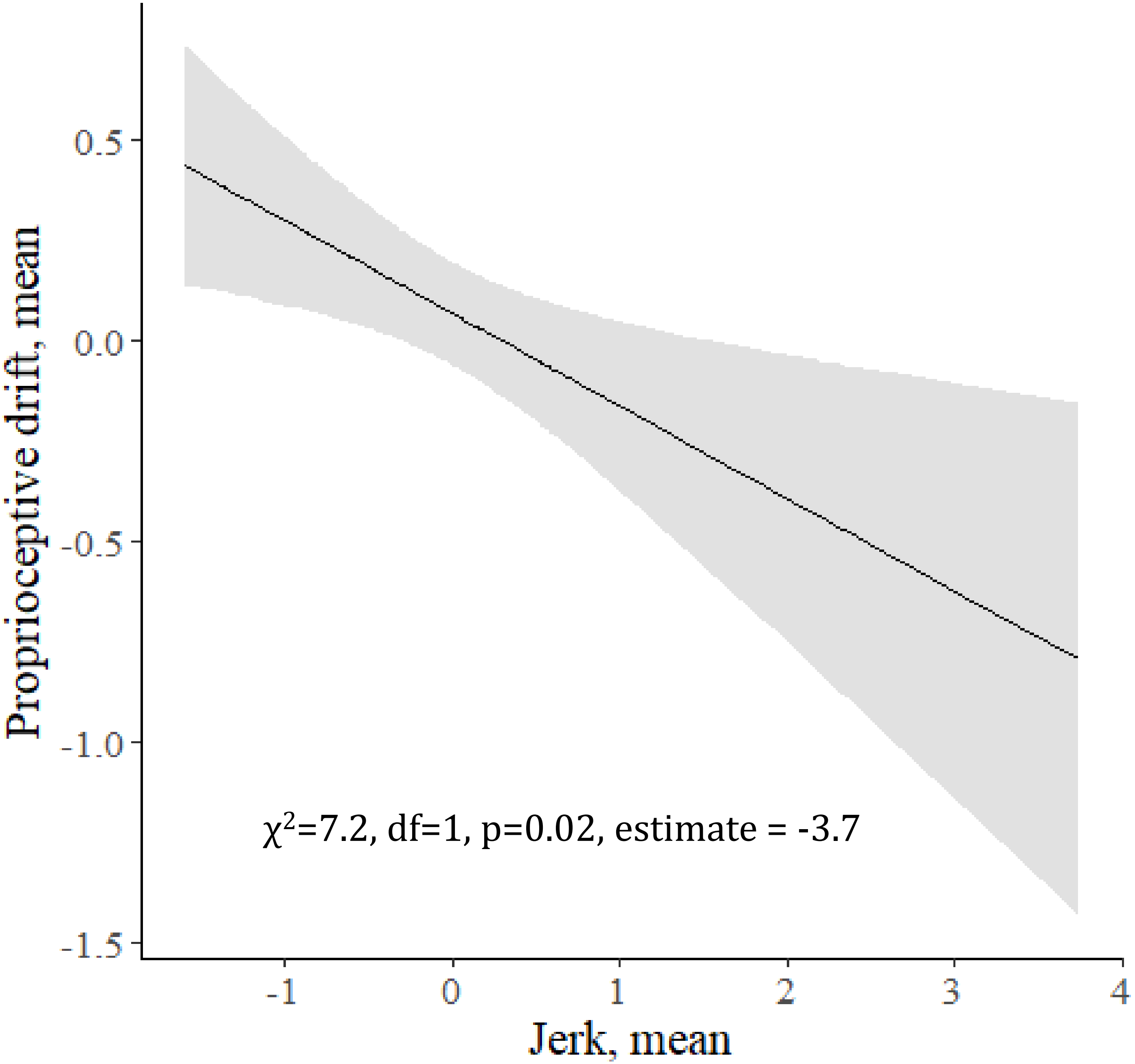
=> Analyzed one joint only [J0]

# Kinematic features

- Distance (m, path of the limb)
- Workspace (cm^2, the smallest rectangle containing all the paths of the limb)
- Volume (m^3, the smallest cube containing all the paths of the limb)
- Effort (J/kg, the work per mass)
- Smoothness (smoothness is quantified using the spectral arc length metric)
- Velocity (m/s)
- Acceleration (m/s^2)
- Jerk (m/s^3).

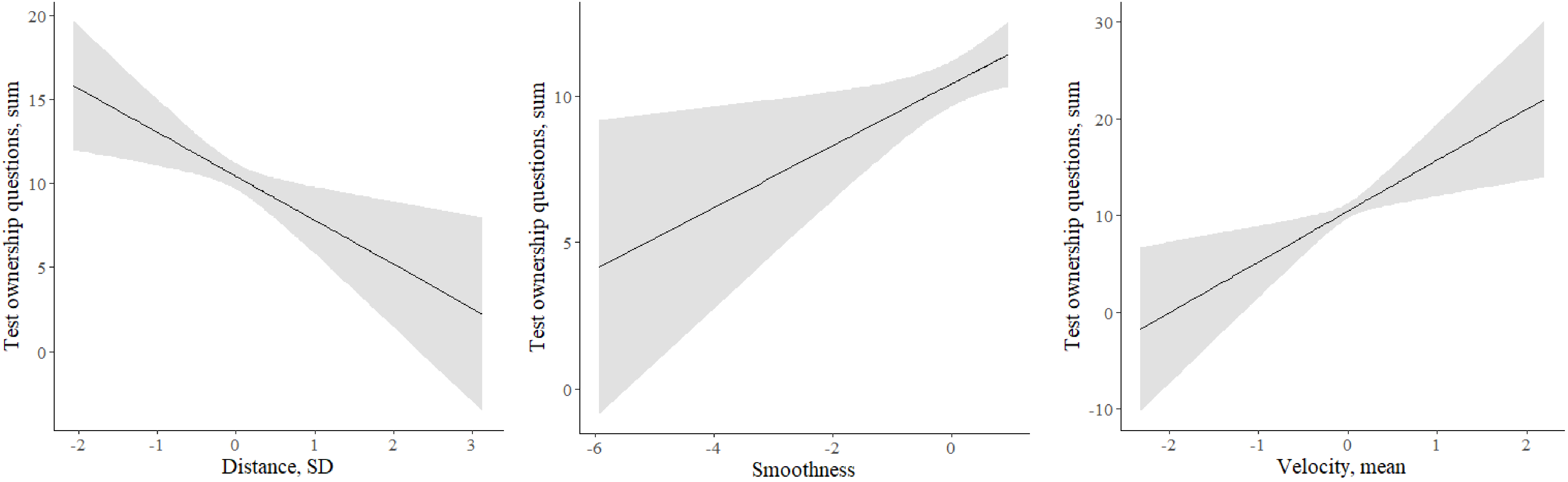
- Workspace, volume and smoothness were calculated as overall measure for each period of stimulation.
- Other features were calculated in each frame (1/30 sec) and then mean (M) and standard deviation (SD) statistics of these features were taken in each stimulation phase.
- With a performance feature (number of dropped objects) there were **14 kinematic features**.

- Preprocessing transformation was applied to all motion features with respect to Interquartile Range (IQR).
- The adaptive lasso regression based on k-fold cross-validation with automatic lambda estimation was calculated for feature selection to avoid model overfitting.
- Selected features were fitted as predictors in two generalized linear models with proprioceptive drift and ownership questionnaire as responses.



Proprioceptive drift, mean
0.5
0.0
-0.5
-1.0
-1.5
-1
0
1
2
3
4
Jerk, mean
χ²=7.2, df=1, p=0.02, estimate = -3.7

Of all motion features for the proprioceptive drift mean, jerk was a significant predictor: **the less jerk the more the drift**.




$\chi^2$=7.9, df=1, p=0.01, estimate = -0.5

$\chi^2$=6.1, df=1, p=0.03, estimate = 0.06

$\chi^2$=8.0, df=1, p=0.01, estimate = 0.9

- For ownership, significant features were smoothness, mean velocity, and SD of distance.
- SD of distance had a reverse dependency with ownership: **less variance of distance reflects better subjective experience**. Since the goal of the participant was to drop the virtual items from the table, less variance of the distance could indicate that participants found the optimal way of dropping items and used this strategy.
- For smoothness and velocity, there was a direct dependency: **the more smoothness of movements and the higher mean velocity the higher subjective ownership experience**.

- All three of these features reflect more **adaptive** and **confident** movements. Therefore, participants with greater motor abilities and with better adaptation to new sensory conditions **may have better multisensory integration mechanisms that are responsible for the ownership illusion**.
- This explanation is partly supported by some evidence that dancers show better integration of proprioceptive signals than non-dancers [Jola, Davis, & Haggard, 2011].

- Otherwise, regression analysis does not require a casual relationship. We can therefore suggest the reverse explanation: **higher ownership illusion was the reason for more adaptive and confident movements with higher velocity and smoothness and less variance of distance**.
- Thus, body ownership may modulate the kinematic characteristics of hand movements.

# Conclusion & Future work

- A kinematic analysis of movements during virtual hand illusion revealed several motion features (distance, jerk, smoothness and velocity) that predicted the ownership illusion.
- The same experiment could be conducted on groups of subjects with different motor abilities, e.g. dancers or sportsmen and non-dancers and non-sportsmen.
- More features could be used, e.g. positions of all joints, rotations of joints and other kinematic features.

# Thank you for the attention!

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The reported study was funded by RFBR in the research project No. 16-36-00394 mol_a