

**THE ROLE OF MULTISENSORY INTEGRATION AND PSYCHOLOGICAL  
FACTORS IN BODY OWNERSHIP: EXPERIMENTAL APPROACHES**

PH.D. THESIS

**GERGELY DARNAI**

SUPERVISORS:

**PROF. JÓZSEF JANSZKY, M.D., D.SC.**

**TIBOR SZOLCSÁNYI, PH.D.**

LEADER OF DOCTORAL PROGRAM:

**PROF. JÓZSEF JANSZKY, M.D., D.SC.**

LEADER OF DOCTORAL SCHOOL:

**PROF. SÁMUEL KOMOLY, M.D., D.SC.**



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## 1. Introduction

How do we feel that we own our body? Why do we feel that they are part of our body when we touch or look at our hands? Questions like these have been discussed in philosophy and psychology for centuries. The **Rubber Hand Illusion (RHI)** is an experimental model invented by Botvinick and Cohen that allows the controlled manipulation of the experience of body-ownership, thus trying to answer these questions. In brief, to elicit this illusion, the participant's real hand is kept out of the field of vision (e.g. behind a screen) while a realistic-like rubber hand is placed in front of him or her. The experimenter uses two paintbrushes to synchronously stroke the rubber hand and the participant's real hidden hand. After a short period (~10-15 sec) the majority of people feel that the rubber hand belongs to them. Since the invention of the "classical" rubber hand illusion several new variants have occurred in neuroscience and psychology. One of them is the **Invisible Hand Illusion (IHI)** by Guterstam and colleagues. They showed that it is possible to elicit an illusion of having an invisible hand that "feels" touches applied to it in empty space in direct view of the participants. To induce this, an experimenter repetitively and synchronously applied brushstrokes to the participant's hand, which was hidden from view behind a screen (similarly to the RHI), and to a portion of empty space in full view of the participant. During the illusion the people experienced a referral of somatic and ownership sensations to the empty space that was fully visible to them, thereby evoking the experience of having an invisible hand.

The *subjective experience* of the RHI and IHI can be quantified with questionnaire including statements about the key perceptual effects of the illusion, such as "It seemed as if I were feeling the touch of the paintbrush in the location where I saw the rubber hand being touched". The most widely used *objective measure technique* is the so-called "proprioceptive drift" – the degree to which people experience their hand to be closer to the rubber hand than it really is.

The present thesis intends to answer two questions related to the aforementioned illusions (RHI, IHI):

I. Can the IHI - that is a visually reduced version of the RHI – be extended by combining irrelevant auditory cues with the common visuo-tactile stimulation used in RHI-like illusions?

II. According to the proprioceptive drift and RHI questionnaire which personality and temperament factors are related to the RHI?

## 2. Sound induced proprioceptive drift in the IHI

In an experiment conducted by our research group, and including a classical RHI and an IHI condition, we found the IHI to lead to both lower subjective ratings of the illusion and smaller proprioceptive drifts than the original RHI. Thus, we decided to associate metronome sound with the view of an artificial hand through a conditioning process in which the classical RHI would be repeatedly elicited in the presence of metronome beats. We hypothesized that following this conditioning process metronome sound would be able to compensate for the lack of the view of an artificial hand in the IHI, thereby enhancing the illusion as compared with its soundless version. Since the results did not support our prediction, but unexpectedly revealed a conditioning-independent influence of auditory stimulation on proprioceptive data, we did not set up a more complex protocol to further examine associative learning in the IHI. Instead, a second experiment was conducted in order to check the results when the same experimental design is used as in the first experiment, except that the between-session RHI is elicited without conditioning sound stimuli.

## 3. Methods

Twenty-six healthy university students participated in both experiments. Participants had no previous experience with the RHI, and were blind to the hypothesis of the study.

Within the pre- and post-conditioning sessions the IHI was elicited in two conditions: in a sound and in a soundless condition. In the sound condition metronome beats were presented to the participants through the headphones in synchrony with visuo-tactile stroking. Metronome beats were short, percussive sounds (stimulus duration: 120 ms; peak sound frequency: 1.2 kHz). In the soundless condition auditory signals were not used. The sequence of the sound and the soundless condition was counterbalanced across subjects both in the pre- and the post-conditioning session. In the conditioning session the classical RHI was repeatedly induced, and metronome beats were presented in synchrony with stroking. The design of the second experiment also consisted of three sessions: a

pre-RHI, a RHI and a post-RHI session. The setup was similar to the first experiment except that no metronome beats were presented in the RHI session.

To measure the main characteristics of the illusion, a questionnaire consisting of 4 statements and proprioceptive drift (in cm) were administered.

#### 4. Results

The analysis of questionnaire data indicated that a few minutes exposure to the classical RHI is able to enhance the vividness of the subsequent IHI.

The combined analysis of the two experiments unambiguously clarified that the use of auditory cues during the induction of the IHI enhances the proprioceptive aspect of the illusion.

#### 5. Conclusion

In our first study we failed to demonstrate that the IHI can be modified by conditioning, our major findings, which might even mask the effect of associative learning, provide relevant contributions to the investigation of multisensory integration and bodily self-consciousness. Most importantly, the results reveal that irrelevant auditory cues presented in synchrony with rhythmic visuo-tactile stimuli can enhance the effect of visuo-tactile integration on proprioceptive updating. Further studies are needed to better understand this kind of complex multimodal interaction.

Secondly, the findings confirm that proprioceptive recalibration gradually increases over time in the RHI-like illusions, and that a longer exposure to such an illusion produces a considerable after-effect on proprioception.

Our data indicate that a few minutes exposure to the classical RHI is able to enhance the subjective vividness of the subsequent IHI.

#### 6. Temperament and syndromes specific susceptibility for RHI

The aim of the study is to explore individual capacity for self-integration, susceptibility to the RHI and the role of temperament factors in the emergence of body schema and body image dissociation. Psychopathological vulnerability, especially to schizophrenia, delusional experiences, anxiety, and interpersonal sensitivity in participants with a vivid RHI response were detected in both healthy persons and patients.

Considering the association among the embodiment scores and schizotypy, magical ideation and interpersonal sensitivity related empathic diffusion we predicted elevated ownership scores in participants with enhanced vulnerability to those symptoms that are related to a weakened ability to differentiate between the self and others.

## 7. Methods

Forty-eight healthy volunteers, including 20 males and 28 females were recruited from a pool of students at the University of Pécs.

Three experimental conditions were used in our study: pre-test condition (no-stroking) when a baseline proprioceptive drift was measured, illusion induction condition (synchronous stroking), and no illusion induction control condition (asynchronous stroking).

To measure the main characteristics of the illusion, a questionnaire consisting of 4 statements and proprioceptive drift (in cm) were administered as well. To measure temperament and psychopathological predispositions SCL-90-R and TCI-R questionnaires were assessed.

## 8. Results

The results indicated that the proprioceptive drift correlated with temperament factors of the TCI-R. Participants with high scores on synchronous proprioceptive drift showed high scores on Novelty seeking – NS – (TCI-R) and low score in Harm avoidance – HA – factors (TCI-R).

Furthermore, participants with high scores on the RHI questionnaire showed high scores in NS, low scores on HA, high scores on Interpersonal sensitivity (SCL-90-R), high scores on Paranoid ideations (SCL-90-R), and high scores on Psychoticism subscales (SCL-90-R).

## 9. Conclusion

Our results suggest that some of the outcome values of the RHI and personality predisposition (TCI-R) and psychiatric symptom factors (SCL-90-R) show close association. These associations provide an opportunity for conducting effective studies to gain important insights into the dynamics of body boundary spectrum disorders in healthy participants and patients, respectively.

## 10. Publications related to the thesis

Kállai, J., Hegedűs, G., Feldmann, Á., Rózsa, S., Darnai, G., Herold, R., ... Szolcsányi, T. (2015). Temperament and psychopathological syndromes specific susceptibility for rubber hand illusion. *Psychiatry Research*, 229(1-2), 410–419. <http://doi.org/10.1016/j.psychres.2015.05.109> **IF: 2.467**

Darnai, G., Szolcsányi, T., Kállai, J., Hegedűs, G., Kincses, P., Kovács, M., Simon E., Nagy, Zs., Janszky, J. (2016). Hearing Visuo-Tactile Synchrony - Sound Induced Proprioceptive Drift in the Invisible Hand Illusion. *British Journal of Psychology*, (in press). <http://doi.org/10.1111/bjop.12185> **IF: 2.254**

### *Publications unrelated to the thesis*

Altbäcker, A., Plózer, E., Darnai, G., Perlaki, G., Horváth, R., Orsi, G., ... Janszky, J. (2015). Problematic internet use is associated with structural alterations in the brain reward system in females. *Brain Imaging and Behavior*. <http://doi.org/10.1007/s11682-015-9454-9> **IF: 4.598**

Altbäcker, A., Plózer, E., Darnai, G., Perlaki, G., Orsi, G., Nagy, S. A., ... Clemens, Z. (2014). Alexithymia is associated with low level of vitamin D in young healthy adults. *Nutritional Neuroscience*, 17(6), 284–288. <http://doi.org/10.1179/1476830514Y.0000000114> **IF: 2.114**

Csathó, Á., van der Linden, D., Darnai, G., & Hopstaken, J. F. (2013). The same-object benefit is influenced by time-on-task. *Journal of Cognitive Psychology*, 25(3), 319–327. <http://doi.org/10.1080/20445911.2012.753875> **IF: 1.198**

Darnai, G., Plózer, E., Altbäcker, A., Perlaki, G., Orsi, G., Kőszegi, T., Nagy, A. Sz., Lucza, T., Kovács, N., Janszky, J., & Clemens, Zs. (2015). The relationship between serum cholesterol and verbal memory may be influenced by body mass index (BMI) in young healthy women. *Ideggyógyászati Szemle* (in press). **IF: 0.343**

Darnai, G., Plózer, E., Perlaki, G., Orsi, G., Nagy, S. A., Horváth, R., ... Clemens, Z. (2015). Milk and dairy consumption correlates with cerebral cortical as well as cerebral white matter volume in healthy young adults. *International Journal of Food Sciences and Nutrition*, 66(7), 826–829. <http://doi.org/10.3109/09637486.2015.1093609> **IF: 1.202**

- Darnai, G., Plózer, E., Perlaki, G., Orsi, G., Nagy, S. A., Horváth, R., ... Clemens, Z. (2016). 2D:4D finger ratio positively correlates with total cerebral cortex in males. *Neuroscience Letters*, 615, 33–36.  
<http://doi.org/10.1016/j.neulet.2015.12.056> **IF: 2.030**
- Darnai, G., Szolcsányi, T., Hegedűs, G., Kincses, P., Kállai J., & Janszky J. (2014). Sound-induced proprioceptive changes in the invisible hand illusion. *Review of Psychology*, 21(1), 91. **IF: -**
- Hegedűs, G., Darnai, G., Szolcsányi, T., Feldmann, A., Janszky, J., & Kállai, J. (2014). The rubber hand illusion increases heat pain threshold. *European Journal of Pain*, 18(8), 1173–1181. <http://doi.org/10.1002/j.1532-2149.2014.00466.x> **IF: 3.218**
- Perlaki, G., Orsi, G., Plózer, E., Altbacker, A., Darnai, G., Nagy, S. A., ... Janszky, J. (2014). Are there any gender differences in the hippocampus volume after head-size correction? A volumetric and voxel-based morphometric study. *Neuroscience Letters*, 570(2014), 119–23.  
<http://doi.org/10.1016/j.neulet.2014.04.013> **IF: 2.055**
- Plózer, E., Altbäcker, A., Darnai, G., Perlaki, G., Orsi, G., Nagy, S. A., ... Janszky, J. (2014). Intracranial volume inversely correlates with serum 25(OH)D level in healthy young women. *Nutritional Neuroscience*, 18(1), 37–40.  
<http://doi.org/10.1179/1476830514Y.0000000109> **IF: 2.114**

*Lectures and Posters related to the thesis*

**First author**

20. Neuroimaging Workshop, Pécs, Hungary 19-20 April 2013

A gumikéz illúzió és kérgi aktivitás

Magyar Pszichológiai Társaság XXII. Országos Tudományos Nagygyűlése,

Budapest, Hungary 5-7 June 2013

A gumikéz illúzió indukciója során aktív ideghálózatok: fMRI vizsgálat

Magyar Pszichológiai Társaság XXIII. Országos Tudományos Nagygyűlése,

Marosvásárhely, Romania 15-17 May 2014

Fantom kéz és műkéz kondicionálása: a testi integritás és a gumikéz illúzió egy újabb példája

11th Alps-Adria Psychology Conference, Pécs, Hungary 18-20 September 2014



Sound-induced proprioceptive changes in the invisible hand illusion

**Co-author**

First World Congress on Personality, Stellenbosch, South Africa 19-23 March 2013

Role of personality factors in the induction of Rubber Hand Illusion

Magyar Pszichológiai Társaság XXII. Országos Tudományos Nagygyűlése,

Budapest, Hungary 5-7 June 2013

A Gumikéz Illúzió: teória és eljárási mód

Magyar Pszichológiai Társaság XXIII. Országos Tudományos Nagygyűlése,

Marosvásárhely, Romania 15-17 May 2014

A gumikéz illúzióra való érzékenységgel összefüggő temperamentum

sajátosságok és pszichopatológiai szindrómák

19th ESCOP, Paphos, Cyprus 17-20 September 2015

Can bodily self-perception be modified by auditory signals? Sound-induced proprioceptive drift in the invisible hand illusion

*Lectures and Posters unrelated to the thesis*

**First author**

10th Magatartástudományi Napok, Pécs, Hungary 25-26 May 2010

Időészlelésünk változatossága: az impulzív viselkedés hatásai

19th MAKOG, Kaposvár, Hungary 27-29 January 2011

Az időészlelésünk változatossága: az impulzivitás hatása az időészlelésre

30th OTDK, Kecskemét, Hungary 7-9 April 2011

Az időészlelésünk változatossága: az impulzivitás hatása az időészlelésre

Kerényi 18: A Kerényi Károly Szakkollégium szakmai hete, Pécs, Hungary 27th April 2011

Az impulzív idő: az időészlelés és az impulzivitás kapcsolata

11th Magatartástudományi Napok, Gödöllő, Hungary 28-29 June 2011

Mentális fáradtság és a megosztott figyelem

Magyar Ideg- és Elmeorvosok Társaságának XXXV. Vándorgyűlése, Debrecen 22-24 November 2012

D-vitamin hatása a kognitív funkciókra

5th European Congress of the International Neuropsychiatric Association, Athens, Greece 30th October 2014 – 2nd November 2014

Iron deposition in subcortical nuclei and Intelligence in young adults  
9th World Congress on Controversies in Neurology (CONy), Budapest, Hungary 26-28 March 2015

Iron deposition in subcortical nuclei inversely correlates with visual memory in healthy young adults (Karger award winner poster)

### **Co-author**

12th Magatartástudományi Napok, Szeged, Hungary 14-15 June 2012

A testkép módosításának hatása a fájdalomérzetre

12th Magatartástudományi Napok, Szeged, Hungary 14-15 June 2012

Mentális forgatási képesség és agytérfogat összefüggésének nemi összehasonlító vizsgálata

12th Magatartástudományi Napok, Szeged, Hungary 14-15 June 2012

Az időészlelés neuropszichológiája

10th Alps Adria Psychology Conference, Lignano, Italy 27-29 September 2012

The impact of the modification of body image on pain perception

Magyar Ideg- és Elmeorvosok Társaságának XXXV. Vándorgyűlése, Debrecen, Hungary 22-24 November 2012

Az alexitímia és D-vitamin kapcsolata

Magyar Ideg- és Elmeorvosok Társaságának XXXV. Vándorgyűlése, Debrecen, Hungary 22-24 November 2012

D-vitamin és az egészséges agyszerkezet – kvantitatív MR vizsgálatok

20. Neuroimaging Workshop, Pécs, Hungary 19-20 April 2013

Strukturális agyi elváltozások internetfüggőségben (előtanulmány)

20. Neuroimaging Workshop, Pécs, Hungary 19-20 April 2013

Az intrakraniális térfogat és a 25(OH)D szint közötti összefüggés vizsgálata fiatal nőkben

20. Neuroimaging Workshop, Pécs, Hungary 19-20 April 2013

Nemek közti különbség a hippocampusz térfogatában

Magyar Pszichológiai Társaság XXII. Országos Tudományos Nagygyűlése, Budapest, Hungary 5-7 June 2013

A gumikéz illúzió hatása a fájdalom-észlelésre

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