EÖTVÖS LORÁND UNIVERSITY
FACULTY OF EDUCATION AND PSYCHOLOGY

Theses of the Doctoral Dissertation

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PSYCHOLOGICAL ASPECTS OF PROPRIOCEPTIVE ACCURACY

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Budapest, 2022

List of publications that the dissertation is based upon

Horváth, Á. (2019). Propriocepció. In F. Köteles & E. Ferentzi (Eds.), *Tanulmányok az interocepcióról. Bárdos György professzor tiszteletére* (pp. 103–131). ELTE Eötvös Kiadó.

Horváth, Á., Ferentzi, E., & Köteles, F. (2019). Proprioceptive accuracy is not associated with self-reported body awareness, body competence, and affect. *Physiology International*, *106*(4), 347–354. https://doi.org/10.1556/2060.106.2019.33

Horváth, Á., Ferentzi, E., Bogdány, T., Szolcsányi, T., Witthöft, M., & Köteles, F. (2020). Proprioception but not cardiac interoception is related to the rubber hand illusion. *Cortex*, *132*, 361–373. https://doi.org/10.1016/j.cortex.2020.08.026

Horváth, Á., Ferentzi, E., Schwartz, K., Jacobs, N., Meyns, P., & Köteles, F. (2022). The measurement of proprioceptive accuracy: A systematic literature review. *Journal of Sport and Health Science*. https://doi.org/10.1016/j.jshs.2022.04.001

Horváth, Á., Vig, L., Ferentzi, E., & Köteles, F. (2021). Cardiac and Proprioceptive Accuracy Are Not Related to Body Awareness, Perceived Body Competence, and Affect. *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.575574

Other studies

Ferentzi, E., Bogdány, T., Szabolcs, Z., Csala, B., Horváth, Á., & Köteles, F. (2018). Multichannel investigation of interoception: Sensitivity is not a generalizable feature. *Frontiers in Human Neuroscience*, *12*, 223. https://doi.org/10.3389/fnhum.2018.00223

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1. Aim of the dissertation

The goal of this dissertation is to shed more light on the association between proprioceptive accuracy and different aspects of healthy psychological functioning (such as affectivity, perceived physical competence, body awareness, feeling of body ownership), and to address methodological issues in proprioceptive accuracy measurement. Firstly, the author will introduce the topic and discuss the related findings. After that, four studies are going to be introduced shortly. That will be followed by a general discussion of the findings.

2. General introduction

2.1. Definition

Proprioception means the (conscious) perception of the information originating from the locomotor system and the skin, that may be modified by related efferent signals (Proske & Gandevia, 2012). To be able to effectively control our movements, we need information about the spatial position of our body, and the position of our limbs relative to each other (Sainburg et al., 1993). For this, we can rely on information from different sources: we can use information coming from outside the body (e.g. vision), but we can rely on information coming from within the body (proprioceptive information) too. The receptors involved in proprioception are called proprioceptors, which are muscle spindles, that inform the central nervous system about the length and rate of muscle stretch, Golgi tendon organs, that process information about tension, and mechanoreceptors located in the joint capsules, ligaments and skin. Also Proprioception is not only affected by afferent (from the receptors to the brain), but by efferent (from the brain) information too. (Proske & Gandevia, 2012)

2.2. Role of proprioception

The consequences of losing or damaging proprioception can tell us a lot about its importance in motor control. Significant impairments in coordination, postural control, and fine manipulation occur (Sainburg et al., 1993). Also, proprioceptive information helps us to determine if a given environmental or bodily change is self-generated or not. The separation of movements generated by the self or the environment is crucial for the separation of the environment and the self itself, and so in for the development of self-awareness (Tsakiris, 2010). Proprioceptive feedback also plays an important role in the development and maintenance of the body scheme and in the feeling of body ownership

(Gallagher, 2005). From the viewpoint of the development of emotions, increased muscle tone reflects a state of readiness, which can be associated with unpleasant experiences, especially in the long term, such as experiencing tension or stress. Through relaxation of the muscles, the negative emotional and physiological experience can be reduced (Rausch et al., 2006).

2.3. Proprioceptive accuracy

There are individual differences in the ability to perceive proprioceptive information, that is called proprioceptive accuracy (Han et al., 2016). One of the most widely used technique is the Joint Position Reproduction test, where a given joint is moved to a target position, and then moved away. After that, the target position have to be reproduced as accurately as possible by the participant. People who engage in regular physical activity have better proprioceptive ability (Ribeiro & Oliveira, 2011). Cognitive factors, such as attentional load and working memory capacity can also influence accuracy (Yasuda et al., 2014). Several studies have shown a relationship between physical and psychological well-being and proprioceptive accuracy. For example a worse ability is associated with a higher chance of getting injured (e.g. Cameron et al., 2003). Chronic neck and back pain may also be associated with worse accuracy (Stanton et al., 2016; Tong et al., 2015). A study of Scholz and colleagues (2001) found, that somatoform patients are generally more accurate when judging the level of muscle tension of the trapezius muscle. Schizophrenia is also characterized by worse proprioceptive accuracy (Chang & Lenzenweger, 2005).

3. Proprioceptive accuracy is not associated with self-reported body awareness, body competence, and affect

3.1. Background

Although proprioceptive acuity plays an important role in physical competence, there are contradictory findings concerning the role it plays in healthy psychological functioning. The current study aims to shed more light on this association.

3.2. Methods

68 young adults participated in our study. We estimated proprioceptive acuity by the reposition accuracy of elbow joint positions. We tested both dominant and non-dominant hand with the ipsilateral and contralateral versions of the Joint Position Reproduction Test. Perceived physical competence, body awareness, and affectivity were assessed using questionnaires (Physical Competence scale of Body Consciousness Questionnaire, Somatic Absorption Scale, and Positive and Negative Affectivity Schedule, respectively).

3.3. Results

The relationship between accuracy and questionnaire scores was investigated with frequentist Spearman correlation and Bayesian Kendall rank correlation. No significant association between proprioceptive acuity and body-awareness, perceived body competence, and positive and negative affect was found. Moreover, the Bayes factors supported the lack of correlation in most of the cases.

3.4. Conclusion

Proprioceptive acuity, measured in the elbow joint, does not play a substantial role in body-awareness, perceived body competence and affect.

4. Cardiac and proprioceptive accuracy are not related to body awareness, perceived body competence, and affect

4.1. Background

Interoception in the broader sense refers to the perception of internal states, including the perception of the actual state of the internal organs (viscerception) and the motor system (proprioception). Aspects of interoception include (1) interoceptive accuracy, i.e., the ability to sense internal changes assessed with behavioral tests, (2) confidence rating with respect to perceived performance in an actual behavioral test, and (3) interoceptive sensibility, i.e., the self-reported generalized ability to perceive body changes. The relationship between aspects of cardioceptive and proprioceptive modalities and their association with affect are scarcely studied.

4.2. Methods

In the present study, undergraduate students (N = 105, 53 males, age: 21.0±1.87 yrs) filled out questionnaires assessing positive and negative affect (Positive and Negative Affect Schedule), interoceptive sensibility (Body Awareness Questionnaire), and body competence (Body Competence Scale of the Body Consciousness Questionnaire). Following this, they completed a behavioral task assessing cardioceptive accuracy (the mental heartbeat tracking task by Schandry) and two tasks assessing proprioceptive accuracy with respect to the tension of arm flexor muscles (weight discrimination task) and the angular position of the elbow joint (joint position reproduction task). Confidence ratings were measured with visual analogue scales after the tasks.

4.3. Results

With the exception of a weak association between cardioceptive accuracy and the respective confidence rating, no associations between and within modalities were found

with respect to various aspects of interoception. Further, the interoceptive dimensions were not associated with state and trait positive and negative affect and perceived body competence.

4.4. Conclusion

In summary, interoceptive accuracy scores do not substantially contribute to conscious representations of cardioceptive and proprioceptive ability. Moreover, non-pathological affective states are not associated with the major dimensions of interoception for the cardiac and proprioceptive modalities.

5. Proprioception but not cardiac interoception is related to the rubber hand illusion

5.1. Background

The rubber hand illusion (RHI) is a widely used tool in the study of multisensory integration. It develops as the interaction of temporally consistent visual and tactile input, which can overwrite proprioceptive information. Theoretically, the accuracy of proprioception may influence the proneness to the RHI but this has received little research attention to date. Concerning the role of cardioceptive information, the available empirical evidence is equivocal. The study aimed to test the impact of proprioceptive and cardioceptive input on the RHI.

5.2. Methods

58 undergraduate students (32 females) completed sensory tasks assessing proprioceptive accuracy with respect to the angle of the elbow joint, a heartbeat tracking task assessing cardioceptive accuracy (the Schandry-task) and the RHI.

5.3. Results

We found that those with more consistent joint position judgements (i.e. les variable error) in the proprioceptive task were less prone to the illusion, particularly with respect to disembodiment ratings in the asynchronous condition. Systematic error, indicating a systematic distortion in position judgements influenced the illusion in the synchronous condition. Participants with more proprioceptive bias toward the direction of the rubber hand in the proprioceptive test reported a stronger felt embodiment. The results are in accordance with Bayesian causal inference models of multisensory integration. Cardioceptive accuracy, however, was not associated with the strength of the illusion.

5.4. Conclusion

We concluded that individual differences in proprioceptive processing impact the RHI, while cardioceptive accuracy is unrelated to it.

6. The measurement of proprioceptive accuracy: A systematic literature review

6.1. Background

Proprioceptive accuracy refers to the individual's ability to perceive proprioceptive information, i.e., the information referring to the actual state of the locomotor system, which originates from mechanoreceptors located in various parts of the locomotor system and from tactile receptors located in the skin. Proprioceptive accuracy appears to be an important aspect in the evaluation of sensorimotor functioning; however, no widely accepted standard assessment exists. The goal of the systematic review was to identify and categorize different methods that are used to assess different aspects of proprioceptive accuracy.

6.2. Methods

A literature search was conducted in 5 different databases (PubMed, SPORTDiscus, PsycINFO, ScienceDirect, and SpringerLink).

6.3. Results

Overall, 1139 scientific papers reporting 1346 methods were included in this review. The methods assess 8 different aspects of proprioception: (a) the perception of joint position, (b) movement and movement extent, (c) trajectory, (d) velocity, and the sense of (e) force, (f) muscle tension, (g) weight, and (h) size. They apply various paradigms of psychophysics (i.e., the method of adjustment, constant stimuli, and limits).

6.4. Conclusion

As the outcomes of different tasks with respect to various body parts show no associations (because proprioceptive accuracy is characterized by site-specificity and method-specificity), the appropriate measurement method for the task needs to be chosen based on theoretical considerations and/or ecological validity.

7. General discussion

The conclusion of the fourth study of this dissertation implies that proprioceptive accuracy can be only used as an umbrella term, and one always needs to specify the method used and the body site measured. This assumption is very relevant when interpreting the findings of the first three studies of the dissertation. We can conclude that perceived body competence,

body awareness and affect is not associated with the Joint Position Reproduction test at the elbow joint (with passive setting and passive/active reproduction), Weight Discrimination ability regarding the tension of arm flexor muscles, but we cannot be sure if it applies to other tests and other body sites too. Also, we can conclude that the strength of the Rubber Hand Illusion is associated with the Joint Position Reproduction Test, with passive setting and passive reproduction. But again, we cannot be sure if it applies to other tests.

From a methodological point of view, a comprehensive investigation of the association between different methods and joints would be desirable. Most of the studies, that investigate the relationship between different proprioceptive accuracy assessment paradigms, only consider a few paradigms (typically two to four), and most of the times the sample size is too small to serve as strong evidence for the lack of association.

Most of the studies in this dissertation utilized a cross-sectional, correlational design, meaning that causal relationships could not be established. For future research, improving proprioceptive accuracy might be a valuable tool to investigate causal relationships.

Given the role of proprioceptive information in movement control, it would be a valuable question to investigate if improving proprioceptive accuracy could make the learning of new motor skills more efficient. However, as one might find it too resource-demanding to train individuals for months to achieve a long-term improvement in proprioceptive accuracy. To solve this problem, it would be possible to use different techniques that improve/reduce proprioceptive accuracy acutely. Different warming-up, stretching an taping techniques were also found to be effective (Ribeiro & Oliveira, 2011). Also, there are procedures that were shown to decrease accuracy, that makes it possible to investigate the effect of reducing proprioceptive accuracy. Cryotherapy and fatiguing the muscle with weight exercises are such procedures (Ribeiro & Oliveira, 2011).

As cognitive factors may influence the outcome of proprioceptive accuracy testing (e.g. (Yasuda et al., 2014), the retention of proprioceptive information in short-term memory is also a valuable question. To investigate this question, we have developed a new test, that measures proprioceptive short term-memory span (i.e., how many joint positions one can retain is short-term memory) (Horváth et al., 2020).

In everyday circumstances, even the execution of basic motor skills (such as reaching for a cup of tea), requires controlling a high number of muscles and joints. Some parts and aspects of the movement may become conscious but because of the limited capacity of consciousness, the most part of the movement pattern will run in an automatic way (Gallagher, 2005). That is why it is important to investigate how proprioceptive information

can affect psychological functioning, an vice versa, in situations when people do not necessary fully attend proprioceptive information. For example, the study of Cacioppo and colleagues (1993) showed that contraction of arm flexor muscles caused a positive evaluative bias in judging neutral stimuli. However, the theory (Cacioppo et al., 1993) has not been tested with an actual arm movement towards or outside the body. A proprioceptor, that can precisely move and/or measure the position of a given joint (for example the elbow), would be perfect for this task

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