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The rubber hand illusion: Maintaining factors and a new perspective in rehabilitation and biomedical engineering?

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Abstract

Feelings of unrealistic body parts are related to deficits in human information processing and can occur as a part of phantom sensations after amputation [8]. Experimentally induced sensoric illusions like rubber hand illusion (RHI) [1] may help to understand basic information processing and could give new ideas for treatment or the rehabilitation process. Factors that are related to modulate sensoric illusions during movement may help to develop new intervention strategies in the rehabilitation of illusory symptoms. The goal of this study was to review the factors affecting persistence of the RHI effect during movement. We selected 13 keywords and searched in the following www.dimdi.de data bases (CCTR93, CDAR94, CDSR93, DAHTA, DAHTA, EA08, ED93, EM00, EM47, HG05, KP05, KR03, ME00, ME60, PI67, PY81, TV01, TVPP). A total of 160 articles were found. Duplicates were removed and the remaining list was filtered with the objective to explore the influence of active or passive movement during experimentally induced RHI. Then we identified six articles which experimentally examined persistence of RHI during active or passive movements. Results indicate that RHI are maintained during active or passive movements due to visual and temporal congruency. During active movements the RHI is more stable or global than in passive movements or during tactile stimulation. Factores like visual and temporal congruency are related to maintain RHI and are discussed in the rehabilitation of phantom sensations regarding new innovations in the design of prosthetics

1 Introduction

After an amputation, feelings of unrealistic body parts are related to deficits in human information processing and can occur as a part of phantom sensations [8]. Those phantom sensations after an amputation are able to lead to feelings of pain which may be localized in a limb that no longer exists. All of these symptoms suggest disturbances in the experience of the body image/body scheme or in general a potential harm to the body matrix concept [24].

1.1 The rubber hand illusion

Botvinick and Cohen [2] showed that the body image/scheme can experimentally be manipulated in healthy volunteers. In this standard paradigm a subject sees a visibly rubber hand being brushed while the real hidden hand of the subject is also synchronously brushed. After a certain time (15 seconds to 10 minutes) this process induces the feeling of ownership of an artificial limb (the rubber hand). Studies demonstrated that on average 25% of the participants do not respond to items that indicate this kind of illusory embodiment [10, 6, 5, 4]. The cause and stability of this effect in responding subjects is attributed to multisensory integration between visual, tactile and proprioceptive information (see Image 1).Also a proprioceptive recalibration towards the rubber hand can be measured. This proprioceptive drift is being measured after the evoking of the illusion. The subject is asked to show the position of his/her real hand. In case of a successful illusion, subjects tend to show the position of their real hands nearer to the rubber hand. Psychological and methodological factors are discussed, whether this indicator is valid [23]. Other indicators that measure the implementation of the illusion are skin temperature, electroencephalography and surveys [24].

1.2 Concepts and evoking factors

Two basic approaches have been postulated [1, 23]. The first is the Bayesian perceptual learning model. It predicts the occurrence of the illusion, even when a neutral object (e g. a pen) without any relationship to the stimulated body part (regarding posture or identity) is stimulated [1]. This may be described as a bottom up process, because its' high probability of temporally co-occurrence of information from different senses that will become bound.
The second is a top down approach, because of the importance of congruence in posture or identity. This may reflect an existing representation of a subjects' body [17, 16, 23]. A more natural hand shaped object in a natural posture evokes a stronger RHI than non natural objects. This suggests an expectation due to a cognitive top down process. This impacts the RHI more than the tactile stimulation. Both approaches may give hints for modulation in the rehabilitation process virtually and in a real environment, which will considered below.

1.2 Rehabilitation and lower limb prosthetics

As mentioned before phantom sensations after an amputation can lead to feelings of pain. Chronic pain after amputation or deafferention in human is considered as a maladaptive process in the central nervous system [18].Reports from Germany show that approximately 50000 amputations were executed, whereas 95% are applied to the lower limps [19]. The rehabilitation process after amputation is therefore an important area because the time to integrate the prosthesis in the body scheme may vary from 14 days to several years [20]. Although some previous studies show that upper limb amputees can be induced to perceive an artificial limb as their own by visuotactile stimulation together with the stump [7], no data for lower limbs are available. To investigate whether subjects can be induced to perceive an artificial limb (prosthesis, robot leg, etc.) as their own two issues are important: First information about RHI and the influence of movement should be collected. Second an idea for a technological application derived from information collected before has to be generated. Both issues are presented in this paper.

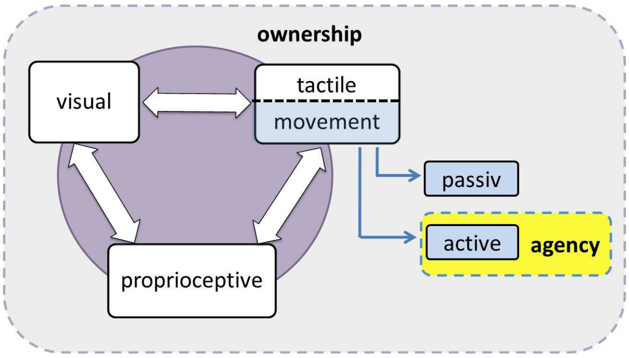

Image 1 Left side: The basic model of RHI boxes. Right side: Extensions (blue boxes).

2 Methods

The most important criteria for finding articles which are related to our topic, was to find articles which experimentally induced RHI. So beside this term itself as important keyword, we need additionally other keywords related to movement. So next we systematically searched in the following www.dimdi.de data bases (CCTR93, CDAR94, CDSR93, DAHTA, DAHTA, EA08, ED93, EM00, EM47, HG05, KP05, KR03, ME00, ME60, PI67, PY81, TV01, TVPP) with various search terms listed in Table 1 to get a maximum of search results. A total of 160 articles were found, duplicates were removed and the remaining list was filtered with the objective to explore the influence of active or passive movement during experimentally induced RHI. Then we identified six articles which experimentally examined persistence of RHI during active or passive movements.

3 Results

To get an overview about the findings see image 2. Our findings allow to extend the basic model of the RHI. The tactile stimulation can be completely replaced by movements and pictured as blue components in image 1. However, in movements a distinction must be made between active and passive ones. Active movement is a self-generated [3] and voluntary action [23, 15] whereas a passive movement is externally generated for example by an experimenter. The important difference is the presence of agency during the active movement condition. The sense of agency involves a strong efferent component [3], "…because only centrally generated motor commands precede voluntary movement." (see [14] p.424). There passive or tactile stimulation only involves afferent sensory signals [15].On the contrary sense of ownership is present through all induction types. Over all conditions the persistence of the illusion seems highly dependent on spatiotemporal congruency (synchrony) between the different information. During all asynchronous conditions the illusion is greatly reduced. The functional principle of the RHI without any movement is the same with movement. These results suggest that the extended model where tactile information is replaced by movement, functional principle remain the same as in the basic model. Apart from that there are different effects especially in the active movement condition. Literature shows the effects in reaction time of ownership and agency during RHI [11]. Only in the synchronous active movement condition a significant speed-up in reaction time was measured. The authors assumed this effect as specific for agency. Another effect which is attributed to agency is a more global illusion [14]. In the corresponding study during synchronous active movement the proprioceptive drift could be measured not only in the stimulating finger but also over the whole hand. The active body was experienced as more coherent and unified than the passive body [15].

	Methods			
Author	*Proprioceptive Drift*	*Questionnaire*		*Reaction Time*
		Ownership	Agency	
Tsakiris et al. 2005	x	-	-	-
Longo & Haggard, 2009	-	x	x	x
Dummer et al., 2009	-	x	-	-
Rosen et al. 2009	x	x	-	-
Sanchez-Vives et al. 2010	x	x	-	-
Taskiris et al., 2010	-	x	x	-

Image 2 Resulting studies and variables

4 Conclusion

4.1 RHI and the influence of movement

The intention of this first review is to use gained knowledge over the RHI and movement to create new ideas for technological application. One central domain is the prosthetics. One of the problems after amputation is the appearance of phantom sensations which can lead to chronicle pain. This is due to the absence of a body part and with it reorganization in the cortical representation of somatic inputs. It may be possible that an artificial hand like in prosthetics, which is embedded into the body image, can reduce these symptoms. In the case of RHI the results suggest that after stimulation the illusion will rapidly disappear. That’s why it is important to maintain the illusion over a longer period of time, where not always tactile stimulation or permanent visual attention is needed [12]. In addition the results show that the RHI paradigm in combination with movements could give a more global and maybe also a more resistant illusion. The sensory information that in return are needed can be generated out of everyday situations, especially active routine movements. The aim of a new therapeutic intervention must therefore be to coach and facilitate these daily movements. On top of that another advantage of maintaining illusionwith active movement can be a speed-up in reaction time [11]. In certain everyday situations of an amputee enhanced capacity of reaction needed, e. g. whereas safely walking is important. Via RHI paradigm it may be possible to integrate an external prosthesis into the body image. The principle of basic and extended RHI model (see Figure 2) lies in a spatiotemporal synchronous stimulation. In contrast asynchronous stimulation may reduce or abort this effect.. That means a malfunctioning control over one’s own actions is emphasized. The apparent domination of visual input in RHI over others plays (beside self-generated actions) a further key role in inducing sense of agency. Given that sense of agency is attended by active movement, we first attach/begin to correct visual feedback through passive movements. After this or in periods of normal mobility the sense of agency could be strengthened by various active movement exercises. At the end the results of the review emphasize that directly comparison between the studies is difficult because different methods were used. The most commonly used method is the questionnaire. But also here the items especially due to the distinction of ownership and agency were experimentally examined only in 2 studies. In others it was simply assumed or not further elaborated. To utilize specific effects of passive or active movement due to RHI it is necessary to use standardized methods to better replicate and compare such findings in the future. Beside this inconsistence, a possible technology should be presented in the next chapter.

4.2 Technological application

For the experimental assessment of RLI during postural movements, a robotic approach is chosen. With this, the RLI maintaining factors and its occurrence during movements can be investigated in experimental testing. One of those should be the transfer of the initial experiment on the RHI from [Bovotnick 1998] [1] to the lower limb as proposed in [22]. Further, the influence of movements on the illusion and its maintaining is a key factor for its application in real prosthetics. Based on the results from [21] a lack of satisfaction in postural motor functioning can be assumed independently from the prosthesis technology used by the particular person. Besides, appearance was assessed as a descriptor for subjective body scheme integration and its significant correlation with the satisfaction during postural movements was shown. In the conclusion of [21] appearance is assumed to be an important factor for body scheme integration and hence to be associated to movements. Thus, investigating such movements should enable to determine and evaluate user-centered parameters for prosthetic design.

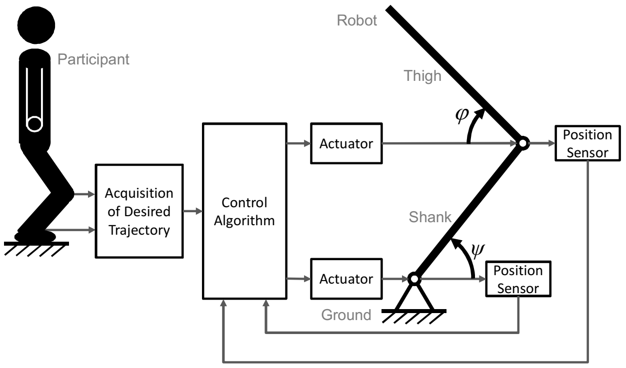

Image 3 Robotic concept for the experimental assessment of RLI during postural movements.

Image 3 presents the functional setup of the robotic approach. It is aiming at the imitation of postural movements of the participants while those are conducting squatting movements next to it. During the experimental investigations, the leg, which is close by the robot, is hidden from the participant’s view. Based on this, the integration of artificial limbs to the subject's body scheme during postural movements can be investigated experimentally. In order to mimic the functionality and appearance of the human foot, shank and thigh as well as the joints of ankle and knee, an appropriate mechanic concept is combined with the hull of a shop-window mannequin, which induces a more realistic outer appearance. The robot is controlled by a control algorithm that acquires the movement data from the participant. To avoid a disturbance of the RLI during the experiments, this acquisition is realized contact-free by a RGB-D sensor as the human-machine interface. Simultaneously, further sensors measure the angular positions of shank and thigh and the control algorithm synchronizes the movements of the robot to the ones of the subject.

Beyond the prevention of a disturbance of the RLI by the contact-free RGB-D sensor, further issues correlated to the occurrence of the illusion have to be considered practical implementation. Examples for such issues are the mechanical design and actuator dimensioning in accordance with psychological and biomechanical requirements. Regarding the mechanical design, the biomechanical requirements demand a comparable size and functionality of the robot. To provide this functionality, a specific actuation power and hence size and acoustics of the applied motors is necessary. Hence, a trade-off between performance, acoustics and installation space has to be determined in this case, as the latter two ones might conflict with the psychological requirements such as the acceptance of the robot as a natural limb.

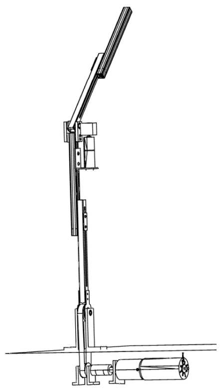

Image 4 Possible technical implementation of the robot

A possible technical implementation of the robots design is given in Image 4. By choosing an undersized actuator for the knee and placing the ankle actuator below the ground of the test stand, acoustic influences are decreased. Further, an adjustment of the lengths of thigh and shank segment is possible.

Further studies will show whether this implementation is able to induce an artificial limb in subjects body scheme.

5 References

[1] Armel, K. C., Ramachandran, V. S: Projecting sensations to external objects: evidence from skin conductance response. Proceedings of the Royal Society B Biological Sciences 2003; 270; 1499-1506.

[2] Botvinick, M., Cohen, J.:``Rubber hands `feel' touch that eyes see'' Nature 1998;391; 756.

[3] Dummer, T., Picot-Annand, A., Neal, T., Moore, C.: Movement and the rubber hand illusion. Perception 2009; 38; 271-280.

[4] Ehrsson, H. H., Spence, C., Passingham, R. E.: That's my hand! Activity in premotor cortex reflects feeling of ownership of a limb. Science 2004; 305; 875-877.

[5] Ehrsson, H. H., Holmes, N. P., Passingham, R. E.: Touching a rubber hand: feeling of body ownership is associated with activity in multisensory brain areas. Journal of Neuroscience 2005; 25(45); 10564- 10573.

[6] Ehrsson, H. H.: The experimental induction of out-of-body experiences. Science 2007; 317; 1048.

[7] Ehrsson, H. H., Rosén, B., Stockselius, A., Ragnö, C., Köhler, P., & Lundborg, G.: Upper limb amputees can be induced to experience a rubber hand as their own. Brain: A journal of neurology 2008; 131(12); 3443-3452.

[8] Goller, A.I., Richards, K.,Novak, S. & Ward, J.: Mirror-touch Synaesthesia in the Phantom Limbs of Amputees. Cortex 2012;

[10] Lloyd, D. M.: Spatial limits on referred touch to an alien limb may reflect boundaries of visuo-tactile peripersonal space surrounding the hand. Brain and Cognition 2007; 64; 104-109.

[11] Longo M. R., Haggard, P.: Sense of agency primes manual motor responses. Perception 2009; 38; 69-78.

[12] Rosén, B., Ehrsson, H. H., Antfolk, C., Cipriani, C., Sebelius, F., Lundborg, G.: Referral of sensation to an advanced humanoid robotic hand prosthesis. Scand J Plast Reconstr Surg Hand Surg 2009; 43; 260-266.

[13] Sanchez-Vives, M. V., Spanlang, B., Frisoli, A., Bergamasco, M., Slater, M.: Virtual Hand Illusion Induced by Visuomotor Correlations. PLoS One 2009; 5; 4. 04.

[14] Tsakiris, M., Prabhu, G., Haggard, P.: Having a body versus moving your body: How agency structures body-ownership. Consciousness and Cognition 2006; 15; 423 – 432.

[15] Tsakiris, M., Longo, M. R., Haggard, P.: Having a body versus moving your body: Neural signatures of agency and body-ownership. Neuropsychologia 2010; 48; 2740-2749.

[16] Costantini, M., Haggard, P.: The rubber hand illusion: Sensitivity and reference frame for body ownership. Consciousness and Cognition 2007; 16(2); 229-240.

[17] Haans, A., Ijsselsteijn, W. A., De Kort, Y. A. W.: The effect of similarities in skin texture and hand shape on perceived ownership of a fake limb. Body Image 2008; 5(4); 389-394.

[18] Flor, H., Nikolajsen, L., Staehelin Jensen, T. S.: Phantom limb pain - a case of maladaptive central nervous system plasticity? Nature Reviews Neuroscience 2006; 7; 873-881.

[19] Blumentritt S., Milde L.: Exoprothetik. In: Wintermantel E, Ha SW (eds.): Medizintechnik. 5. überarbeitete und erweiterte Auflage, Berlin-Heidelberg: Springer-Verlag, 2009: 1753-1805.

[20] Mayer, A., Kudar, K., Bretz, K., Tihanyi, J.: Body schema and body awareness of amputees. Prosthet Orthot Int 2008; 32(3); 363-82.

[21] Christ, O. Beckerle, P. Rinderknecht S., Vogt, J.: Usability, satisfaction and appearance while using lower limb prostheses: Implications for the future . Neuroscience Letters 2011; 500 (S1); e50.

[22] Jokisch, M, Preller J, Schropp A, Christ O, Beckerle P, Vogt J.: The rubber hand illusion paradigm transferred to the lower limb: A physiological, behavioral and psychometric approach. International Journal of Psychophysiology in press.

[23] Tsakiris, M., Haggard, P.: The rubber hand illusion revisited: visuotactile integration and self-attribution. J Exp Psychol Hum Percept Perform. 2005; 31(1); 80-91.

[24] Moseley, G.L., Gallace, A., Spence, C.: Bodily illusions in health and disease: Physiological and clinical perspectives and the concept of a cortical 'body matrix'. Neurosci Biobehav Rev 2012; 36(1); 34-46.