Identification of haptic paths with different resolution and their effect on body scheme illusion in lower limbs

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Abstract
New research in the field of prosthesis showed a lack of satisfaction of amputees with their prosthesis and the prosthesis shaft, despite of the technology that is used. Correlative studies show a relation between satisfaction of the prostheses user and appearance. Interpreting appearance as a descriptor for body scheme integration, due to the significant correlation with voluntary movements, the consideration of this human factor is expected to be most useful to optimize biomechanical functionality. To enhance this human factor in the future the transfer of the rubber hand illusion (as a neuroscientific paradigm) to the foot is tested within an experimental setup that is able to identify different haptic paths and to examine the effect of these paths on the rubber foot illusion. First results show small effects during the evoking of the rubber foot illusion. For now, different haptic stimulation paths have no impact on the evoking of the rubber feet illusion. Consequences for the optimization of biomechanical functionality within the concept of appearance and the measurement of the satisfaction of the prosthesis user in the future are discussed.

1 Introduction
New research in the field of prosthesis showed a lack of satisfaction of amputees with their prosthesis and the prosthesis shaft, despite of the technology that is used [2, 3, 4]. Not only dissatisfaction is observable, also inconsistencies in the results may show a kind of resignation regarding the opinion of prostheses users [3]. In N=29 transfemoral amputees the satisfaction rating of the prosthesis showed significantly positive correlations to the experiences of problems due to a swollen stump (r =.394). At the same time satisfaction with the transition from standing to walking was also significantly positive correlated to the experiences of problems due to a swollen stumps (r =.556). These inconsistent results indicate that users may accept a certain amount of dissatisfaction and hence show the relevance of satisfaction as a human factor. Beside satisfaction, the feeling of security seems to be directly correlated to the flexibility of prostheses. Problems in changing gait velocity were significantly negative correlated to the feeling of security during spontaneous movements (r = -426).Because flexibility can be seen as a part of functionality, this shows a connection between predisposition human factors and the enabling technical factors. Moreover, an impact of balance and confidence on the fear and incident of falling is shown and a correlation between appearance and functionality during walking (r = .634) and sitting (r = .580) can also be observed [4]. Interpreting appearance as a descriptor for body scheme integration [5] due to this significant correlation with voluntary movements, the consideration of this human factor is expected to be most useful to optimize biomechanical functionality.

1.1 Neuroscientific paradigms and optimized biomechanical functionality
At the same time technical improvements enhance the function of active prostheses, new ideas show an enhancement of the user centered development process [12,13] and the introduction of neuroscientific paradigms like the rubber hand illusion/RHI to the lower limbs [7,14,1]. RHI is a neuroscientific paradigm that is used to perceive an artificial limb as one’s own. Studies show that upper limb amputees can be induced to perceive an artificial limb as their own by visuotactile stimulation together with the stump [8, 9]. Thus, body scheme integration or body scheme recalibration [8, 6] due to tactile and visual stimulation seems to be possible in the upper extremities. Although no data for lower limbs are available a possible new way to optimize biomechanical functionality in lower limb prosthesis users and possible new way to enhance appearance could be identified.

In healthy subjects, the RHI paradigm was transferred to the foot with different results [1, 14]. The proprioceptive drift values (the proprioceptive drift describes the tendency of subject after a successfully evoked illusion to locate his or her real limb nearer to the artificial object than in a control condition) showed less significant changes than data from surveys [1].Regarding psychophysiological measurement e.g. temperature differences in the upper extremities were found [10]. Regarding the foot no such differences were observable [1]. Due to this, only survey and proprioceptive drift data seem to give valid information about a successfully induced rubber foot illusion. This paper aims to give an idea of an experimental setup (with
the help of proprioceptive and survey data), that is able to test whether a previously identified high resolution stimulation path (high resolution receptive fields) on the surface of the foot will elicit a better illusion than a low resolution stimulation path.

2 Methods

2.1 Identification of haptic paths

In the first study (S1) 34 subjects (22 females) with a mean age of $M=26$ and $SD=8.1$ years participated. With the two point threshold method a high and a low resolution path on the left foot surface were identified. For this, a slide gauge was used to observe the threshold in different areas of the skin that were previously identified (theoretically) with different kind of sensitivity due to characteristics of the receptive fields (see figure 1). During the measurement subjects were asked whether they are feeling one or two pins on their skin. Before touching the skin, the pins of the sliding gauge was fixed randomly under or over the threshold of the subject until the threshold was detected. Subjects with incongruent results (higher values in the higher resolution areas) or previously reported illness were excluded. The remaining 19 healthy subjects (11 females) with a mean age of $M=24$ and $SD=4.5$ years participated in the second study (S2). All subjects showed significant high and low resolution paths on their left foot surface. In S2 the RHI was transferred to the foot.

![Figure 1: Example for the measurement of the two point threshold method on the surface of the foot.](image1.png)

2.1 Rubber hand illusion transferred to the foot

All subjects were randomly assigned to one of the permutated stimulation conditions: Synchrony stimulation and cheated stimulation. In the synchrony stimulation condition subjects saw the movement of the brush on the surface of the artificial limb.

![Figure 2: Measurement of the proprioceptive drift with a sliding light after the stimulation phase.](image2.png)
At the same time they felt the movement of a brush on the skin of their real foot (see figure 3). The independent variable was the stimulation of the high/HR or the low/LR resolution path of the skin or the control condition (seeing a cheated stimulation). The dependent variables were the proprioceptive drift (see apparatus in figure 2) and a modified survey from [11]. The survey was translated into the German language and comprises three body scheme dimensions: Ownership, location and agency. Ownership describes the way a subject thinks that an artificial limb belongs to her/him. Location describes a person's believe to locate this artificial limb. Agency describes the believed control over an artificial limb.

All data were calculated using SPSS 15 (student's t-tests with Bonferroni alpha adjustment) because of our directional hypotheses.

![Figure 3: Example of the experimental setup of the rubber foot paradigm.](image)

### 3 Results

The results of S2 showed no significant differences between HR and LR conditions in the survey and the proprioceptive drift data. There were no significant differences in the proprioceptive drift data between HR and control condition and LR and control condition with lower values in the control conditions. The survey data showed significant differences between HR and control condition in the dimensions ownership and location. Finally there were significant differences between LR and control condition in the dimension ownership and location. Regarding the dimensions agency no significant results were found. In every case the control condition showed lower values.

### 4 Conclusions

The aim of this paper was to give an idea of an experimental setup that is able to test, whether a previously identified high resolution stimulation path (high resolution receptive fields) on the surface of the foot will elicit a better rubber foot illusion than a low resolution stimulation path.
4.1 Experimental setup

Although the experimental setup of both studies worked fine, several limitations of the methods which were applied should be discussed. The two point threshold method is valid instrument, but identified a lot of people that showed inconsistent results (N=15). A more detailed analysis of subjects regarding health related factors should be applied in further studies for a better subject selection. Maybe an “online” ROC identification process could help. The process of body scheme integration and recalibration [6,10] is complex and some ideas are not fully understood yet. If the investigation of healthy subjects is able to uncover complex ‘inconsistent’ covariates, what would the investigation of amputees in different body scheme recalibration phases in future show? Further studies should examine the inconsistencies that we could demonstrate. A systematic documentation could help to select the optimal sample and could raise the sample size while preparing a replication study. The stimulation during the RHI paradigm in study 2 excluded the asynchrony condition. From several studies [7, 10] it is known that an asynchrony condition will reduce the effect of the illusion. Including two different haptic paths, this should be tested also for the lower limbs [1, 14] because of possible reciprocal or emergent effects.

4.2 Haptic paths and illusion

The authors’ results indicate a strong influence of visual channel during the illusion [10]. The effect of the previously found high and low resolution paths have the same influence on eliciting the illusion, although they also showed significant differences regarding their psychometric properties. Regarding the sample size (see discussion in the chapter before) a replication should be done. Further studies should evaluate the reason in the differences between survey data and proprioceptive data that have been previously found [1, 14]. Within this evaluation a valid indicator for a maintaining illusion could be identified and used for the technically supported enhancement of the body scheme integration of prosthesis and the enhancement of appearance in prostheses users.

4.3 Optimized biomechanical functionality

As described before, body scheme integration seems to be an important factor in the design of active prostheses. To transfer the neuroscientific paradigm of the rubber hand illusion to the foot is a first approach to change the body scheme integration in a way it could be used for lower limb amputees and to test whether useful ideas for the design process can be derived. Further studies should identify factors that maintain and stabilize the illusion. Once this can be realized an innovative method for the user centered design of lower limb prostheses could be used to enhance the satisfaction during the use of prostheses, like this was considered in [12, 13].

References


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