Research Paper

Effect of electrical stimulation of receptive fields in people with lower limb amputation on variables of gait

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A B S T R A C T

People with amputation may perceive phantom limb sensations or pain in the amputated body part when ipsilateral body-regions are stimulated. These body-regions are called receptive fields. This study assessed whether receptive fields change in size and position over the course of one month in people with trans-tibial amputation and whether electrical stimulation of these fields in synchrony with walking affects phantom sensations and variables of gait. Thirty-one subjects participated in this study. Receptive fields were mapped seven times over a one month period. Thereafter, the effect of electrical stimulation in synchrony with walking was compared to placebo stimulation in an acute setting with a randomized, single-blind gait analysis in 18 participants. Results showed that receptive field size and position presented an adequate degree of consistency (difference in point of first response position of 4.9 ± 4.8 cm and overlap of total receptive field area of 54.3 ± 35.0 %) for future use of electrical stimulation. Gait parameters for everyday activities (speed, gait width, % stance and swing phase) as well as perception of phantom pain were not altered to a clinically relevant degree by electrical stimulation and no negative effects were reported. In conclusion: Location and size of receptive fields are consistent enough for daily electrical stimulation without laborious daily assessment. If applied acutely, no significant effect on gait or pain could be detected. However, results are promising enough to test chronic application of electrical stimulation during gait in a long-term setting.

1. Introduction

1.1. Background

Amputation is the removal of the whole or part of a limb by cutting through bone or joint (Ajibade et al., 2013) and a common reality for numerous people. In 2012, 0.04 % of all insured people in Germany had at least one amputation (Heyer et al., 2015) and in the USA, about 185'000 individuals undergo amputations annually (Ziegler-Graham et al., 2008). An amputation represents a relevant reduction in the quality of a patient's life. One factor contributing to the reduced quality of life is phantom limb pain. Phantom limb pain is a type of chronic neuropathic pain occurring in 45–85 % of patients who undergo a major amputation and is disabling for nearly two thirds of them (Kooijman et al., 2000). Phantom sensations, on the other hand, are non-painful phantom limb sensations and they occur in up to 90 % of the patients within the first six months after amputation (Jensen et al., 1983).

Receptive (or reference) fields are defined as ipsilateral body regions in which contact or electrical stimulation evokes phantom sensations or phantom limb pain. The changes in receptive field location and size caused by amputation have been observed in animals (Byrne and Calford, 1991; Calford and Tweedale, 1991) and in upper extremities in humans with upper extremity amputation (Ramachandran and Hirnstein, 1998). In humans, after amputation of one of the upper extremities, mapping of the receptive fields on the face of a subject has been performed (Ramachandran and Hirnstein, 1998). The most likely cutaneous skin regions to bear these receptive fields after an amputation are the areas closest to the amputated body region on the Penfield homunculus (Ramachandran and Hirnstein, 1998) (for example the shin region for trans-tibial amputations). Multiple methods as mirror therapy, motor imagery or two point discrimination have attempted to treat phantom limb pain (Weeks et al., 2010; Diers and Flor, 2013; Dwornik et al., 2015) as well as improve gait in people with prosthetic

Table 1
Sample size group characteristics. Data is given as mean $\pm$ SD = Standard deviation. kg = kilogram. cm = centimetres. BMI = body mass index. N = number of participants.

		N	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m²)	Time since amputation (years)
Receptive fields phase	**Male**	26	59.0 ± 12.7	93.5 ± 17.9	179.3 ± 7.0	31.3 ± 6.4	13.3 ± 12.7
	Female	5	45.6 ± 20.0	64.8 ± 12.1	169.2 ± 4.2	24.3 ± 4.3	3.2 ± 2.2
	Total	31	56.8 ± 14.6	88.2 ± 20.2	177.4 ± 7.7	30.0 ± 6.6	11.7 ± 12.3
Gait analysis phase	**Male**	17	58.4 ± 14.2	89.9 ± 10.2	178.9 ± 6.2	30.2 ± 3.9	11.1 ± 10.9
	Female	1	71.0 ± 0.0	67.0 ± 0.0	176.0 ± 0.0	23.3 ± 0.0	4.8 ± 0.0
	Total	18	59.1 ± 14.1	88.4 ± 11.4	178.7 ± 6.0	29.8 ± 4.2	10.8 ± 10.7

limbs (Darter et al., 2013; Barton et al., 2014; Samitier et al., 2016). This, as optimizing gait characteristics as well as phantom limb pain can influence residual limb comfort, affect the efficiency of ambulation and reduce compensatory movements that over time may prove harmful to the individual by causing back pain or ostheoarthritis (Baker et al., 2016).

As phantom sensations and phantom limb pain may be related to inconsistencies of motor intention, sensory feedback and corresponding activation of the brain frontal and parietal areas (Diers et al., 2010; McCabe et al., 2005), a chronic enhancement of sensory feedback could help overcome phantom limb pain as well as positively influence gait patterns by improving gait safety. This, as a restored sensory feedback coming from an amputated body part would weaken the discrepancies detected by the central nervous system between the predicted and excuted sensory and motor activities. Finally, this could improve quality of life of people with amputation.

Recently, an electronical receptive field stimulation system was developed (Phantom Stimulator, CortXsensorics GmbH, Spaichingen, Germany), with the intent of providing sensory feedback via electrical stimulation of receptive fields and transfer the information of the foot touching the ground during walking. For this purpose, a high degree of consistency in size and position of these fields is needed over time. Yet, this consistency of size and location of the receptive fields over time in people with a transtibial amputation has not been systematically examined. However, this is essential to know in case these fields should be used for repetitive electrical stimulation without new assessment each time. Furthermore, the effect of electrical stimulation of the receptive fields when walking using this so called Phantom Stimulator on gait parameters as well as on phantom sensations and phantom limb pain, has not been examined.

Therefore, the present study aimed to test whether there is a change in size and position of the detected receptive fields over a period of 31 days and whether this change would be large enough to challenge the correct use of the Phantom Stimulator. Furthermore, the acute effect of the electrical stimulation on selected gait parameters (step width, stance and swing phases percent and self-selected walking speed) as well as on phantom sensations and phantom limb pain was compared to

a placebo condition. The focus of the evaluation was set on parameters directly relevant to everyday life of the subjects, i.e. self-selected gait speed as well as gait symmetry between the stance and swing phase of the prosthetic leg (Po-Fu Su et al., 2007) as it may theoretically be advantageous for people with amputation to walk with a compensatory pattern to improve biomechanical performance of the prosthetic device (Baker et al., 2016). We hypothesized that receptive fields would be stable enough such that the electrodes could be placed in the same position over 1 months' time without losing contact with the receptive fields and that gait variables would remain unchanged with acute electrical stimulation.

2. Experimental procedures

2.1. Subjects

Subjects were recruited from one rehabilitation centre (Rehaklinik Bellikon, Schweiz). Inclusion criteria for the detection and evaluation of the receptive fields, and thus the first phase of the study, were a minimum of one transtibial amputation for at least six months and age above 18 years. For the second phase with the electrical stimulation of receptive fields, exclusion criteria were: bilateral amputation of the lower extremities (n = 2), absence of receptive fields (n = 3), no reaction to the stimulation electrodes ((n = 1; see below), not enough mobility to walk without support (n = 1) or receptive fields in the region of the prosthesis preventing the use of the Phantom Stimulator (n = 3), carrying implanted electrical devices (defibrillator or pacemaker; n = 0) or being pregnant (n = 0). Three subjects were excluded due to time constraints. Subjects' characteristics of the first (receptive field) and second (gait analysis) phase of the study are displayed in Table 1.

The study was approved by the ethics committee of northwest and central Switzerland (NCT03348605). Written informed consent was obtained from all participants.

Table 2
Timeline and evaluated variables of the experiments.

|		Receptive fields phase (31 days)	Gate analysis phase (1.5 h)
Day 1	Meeting 1	Tester X size of each receptive field	–
Day 2	Meeting 2	Tester X size of each receptive field	–
Day 7	Meeting 3	Tester X size of each receptive field % overlap of each field compared to day 1, difference in distance to day 1	–
Day 14	Meeting 4	Tester Y size of each receptive field % overlap of each field compared to day 1, difference in distance to day 1	–
Day 21	Meeting 5	Tester X size of each receptive field	–
Day 28	Meeting 6	Tester Y size of each receptive field	–
Day 31	Meeting 7	Tester X size of each receptive field % overlap of each field compared to day 1, difference in distance to day 1	–
Between day 31 and 38		–	Three blocks of gait analysis and questionnaire
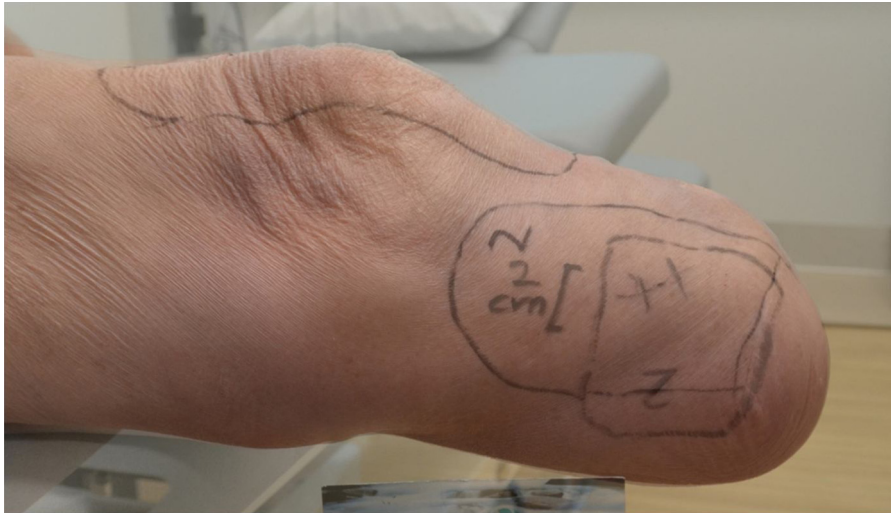
Fig. 1. Two consecutive assessments of receptive field no. 2, labelled with marker on skin and the number 2 on the lower outer part of the stump, are shown. The two crosses inside the receptive field mark the point of the first noticed feeling by the participant. The 2-cm line is serving as reference for the size.

2.2. Procedure and instruments

During the first phase of the study, the receptive fields of the subjects were mapped in seven meetings by two different testers (see Table 2). In these meetings, the receptive fields were examined with a conventional sensitive toothbrush (Candida Sensitive Ultra Soft, Migros, Zurich, Switzerland), marked with a conventional black eyeliner (Color Icon Kohl Liner Pencil, Wet n Wild, Los Angeles, USA) and photographed (Nikon D5100, Nikon, Tokyo, Japan) Fig. 1 in the presence of a reference size. If no plane picture of the whole receptive field could be taken, it was subdivided in multiple pictures. This was done to ensure adequate calculation of the size and movement parameters. The pictures taken in this first phase of the study were evaluated using Photoshop CC 2017 (Adobe, San José, USA) by comparing the size of the receptive field to the photographed reference size. The examined parameters were the number, the size of the receptive fields and the percent overlap ($\%overlap = \frac{overlapping\ area\ receptive\ field}{total\ area\ receptive\ field} * 100$) as well as the distance of the centre of the area of the receptive fields between the respective meetings (for details see Table 2). A relevant change in size and position was defined as a challenge to the correct use and function of the Phantom Stimulator over a period of 31 days. The area needed for the electrical stimulation is given by the 4×4 cm size of the 4 electrodes needed by the phantom simulator which results in 64 cm^2. From this calculation, we consider a shift of the centre of the receptive-field-area of 8 cm or more to be a challenge for the functionality of the Phantom Stimulator as this movement would be out of range for 4 electrodes of 4×4 cm of size.

After the mapping the participants were asked to communicate verbally what sensation was evoked during the stimulation of the receptive field and which area of the phantom limb was perceived.

Between the first mapping phase and the second gait analysis phase of the study the appropriate receptive fields for the stimulation had to be selected. The exclusion criteria are as described above (section "Subjects").

During the second, single blind, randomized gait analysis phase, participants had four electrodes (4×4 cm) placed on the selected receptive fields and an insole containing two force sensors underneath the prosthetic heel and toes placed into the shoe of their prosthesis (see Fig. 2). The Phantom Stimulator applied a biphasic current at the moment of ground contact measured by the insole to the receptive field. The amount of applied current was previously defined as the lowest amount felt by the participant at the site of the placed electrodes. The frequency was fixed at 50 % of the maximal applicable amount by the
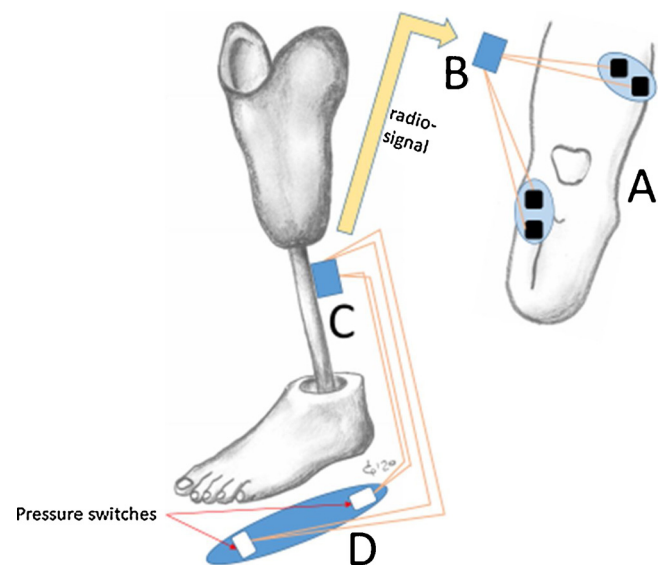

Fig. 2. Representation of the setup of the Phantom Stimulator as represented on http://cortxsensorics.com/products/phantom-stimulator/ (Simplified graphics by T. Koller).

system.

Subjects then performed three blocks of two times walking for 80 m (10×8 m) on an optical tracking area (Optogait, Microgate Srl, Bolzano, Italy) working with 8 bars of one meter containing 96 LEDs each, communicating on an infrared (visible) frequency with the same number of LEDs on bars at the opposite side of the tracking area. The first block of walking served as familiarisation/practice (no electrodes in place yet). The second and third blocks of walking served for gait analysis with either electrical stimulation (stimulator on) or placebo (stimulator off) and were performed in randomized order. Each block was directly followed by a questionnaire asking for the presence of phantom sensations or phantom limb pain.

2.3. Data analysis

During the second phase of the study step length and width (as a measure of gait security; Hiroaki et al., 2009) and % stance and swing phase of the amputated leg and walking speed were averaged over each block of gait analysis. Only the values of the amputated leg were

analysed and compared. The focus of the evaluation was set on parameters directly relevant to everyday life of the subjects. This as it may be theoretically advantageous for people with amputation to walk with a compensatory pattern to improve biomechanical performance of the prosthetic device (Baker et al., 2016). These relevant outcome measures would be self-selected gait speed as well as gait symmetry between the stance and swing phase of the prosthetic leg (Po-Fu Su et al., 2007). The questionnaire compiled at the end of every block of gait analysis evaluated the presence of phantom sensations or phantom limb pain. The quantitative degree of phantom sensations or phantom limb pain was assessed with a series of yes/no questions and visual analogue scales. The qualitative assessment of the phantom sensations was evaluated in an open question format.

Statistical evaluations were performed with the statistical software SPSS (IBM SPSS Statistics, Version 24, 64-Bit). All data was analysed for normality of distribution using the Shapiro-Wilk test. If the data was normally distributed, a paired *t*-test was used, if no normal distribution was present, even after logarithmic transformation, a Wilcoxon signed-rank test was used. A 95 percent confidence level was used to determine statistical significance.

3. Results

3.1. Receptive fields

In Fig. 3, the position of the detected receptive fields in relation to the human body is shown. Here, the majority of the detected receptive fields are located in the stump of the trans-tibial amputees and a decrease in number of the receptive fields with increasing distance to the amputation site is visible.

The number of detected receptive fields for each of the seven meetings is represented in Fig. 4. A minority of participants (9.7 %) showed no receptive fields at all. Off all the 97 receptive fields present at day one, 20 disappeared over the 31 days. On the other hand, 12 receptive fields originated between day two and 31.

In a quarter (25.4 %) of the receptive fields, mechanical stimulation evoked a reaction in the region of the foot, whereas 74.6 % of the receptive fields evoked reactions in regions situated between ankle joint and stump. The evoked feelings ranged from prickling (positive/neutral) to distressing pain and their relative percentages are displayed in Table 3.

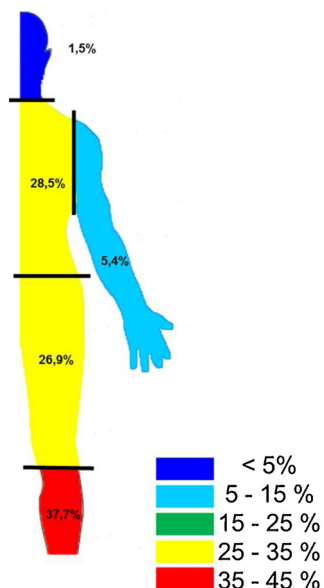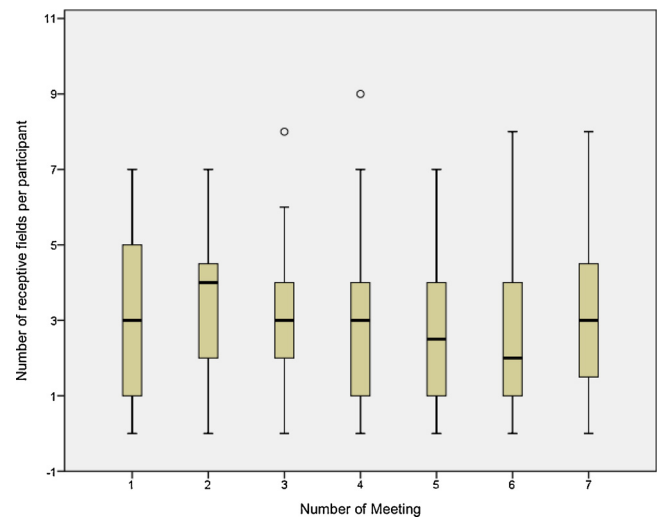The mean size of the detected receptive fields over 31 days was

Fig. 4. Number of detected receptive fields per participant for each of the seven meetings. Meeting 4 and meeting 6 were always performed by a different tester. Note: Box plots include the interquartile range (IQR) with the median shown as black line. The whiskers represent the maximum of 1.5 IQR. Outliers are represented as empty dots.

Table 3
Evoked feelings by the mechanical stimulation of the receptive fields.

		Count	%
Negative	Painful	3	2.3
Positive/Neutral	Prickling	97	74.6
	Stroking	8	6.2
	Pulsating	22	16.9

$117.5 \pm 222.3 \ cm^2$ (see Fig. 5). The mean change in size from day 1 to day 31 was 118.4 ± 268.7 %.

The data regarding the changes in size in percentage between the different measurements compared to meeting 1 are shown in Table 4. Here, a significant growth in size from meeting 1 to meeting 4 is visible. The movement of the centre of area of the receptive fields over time compared to meeting 1 is shown in Table 5. The overlap never falls below 44.8 ± 35.5 % and the movement never exceeds 5.3 ± 5.4 cm.

Fig. 3. Position of the receptive fields in percent over all participants and all days.
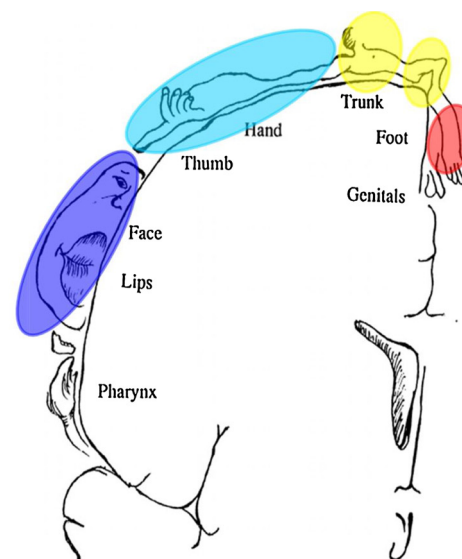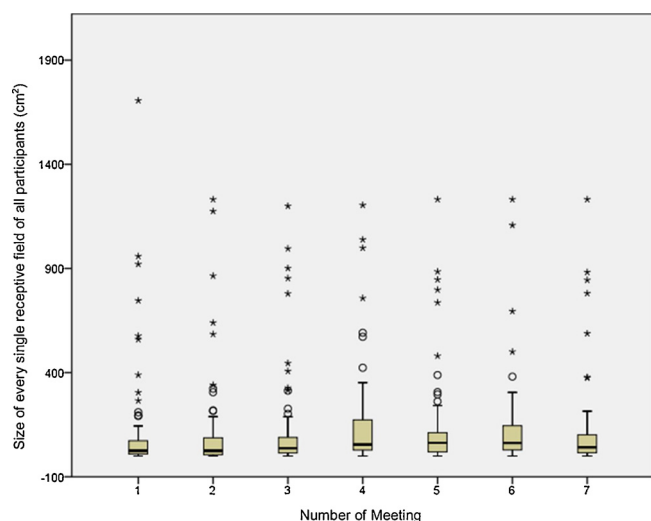
Fig. 5. Size of the receptive fields. Note: Box plots include the interquartile range (IQR) with the median shown as black line. The whiskers represent the maximum of 1.5 IQR. Mild outliers are represented as empty dots and extreme outliers as stars.

3.2. Gait analysis

In Table 6 the recorded data concerning the length parameter (step width), the percentages of the gait cycles (stance phase and swing phase) and the speed parameter (mean speed) of the two analyses with the Phantom Stimulator of the amputated leg as well as their statistical analysis are displayed. No significant differences between electrical stimulation on and off conditions were measured in the current study.

The electrical stimulation performed by the functional Phantom Stimulator evoked vivid phantom sensations within the phantom foot in 33.3 % of the tested subjects. In 44.4 % of the subjects an electrical over-stimulation of the receptive field at the minimum current output of the Phantom Stimulator evoked local sensations at the site of the electrodes and in 22.2 % of the subjects an electrical under-stimulation of the receptive fields at the maximum current output of the Phantom Stimulator caused no sensations at all. 33.3 % of the participants had feelings concerning the phantom foot also in the placebo situation of the Phantom Stimulator and 5.6 % of the participants had local sensations at the electrodes evoked whereas in 61.1 % of the participants no sensations were evoked.

4. Discussion

4.1. Receptive fields

The observed spatial distribution of the receptive fields on the participants bodies is consistent with the theory first presented by Penfield and Rasmussen (1950), describing the sensory body representation in the somatosensory cortex known as Penfield homunculus. The consistency with this theory is given as the probability to detect a receptive field decreases with increasing distance to the amputation site. In accordance with the theory, the results also show a higher percentage of phantom sensations concerning the shin instead of the foot. This is expected as the shin is in closer proximity to the amputation point on the homunculus representation.

The size and positioning of the receptive fields detected during the seven meetings of the first study phase showed a sufficient degree of consistency to allow an unobstructed functionality of the Phantom Stimulator during 31 days in the future. The fact that the mapping performed by different testers did not show any obstucting differences for the Phantom Stimulator supports the findings concerning the spacial consistency of the receptive fields. However, to ensure the correct application of the Phantom Stimulator's current, the most appropriate receptive field for the electrical stimulation needs to be chosen The selection should be based on position (not in the shaft region) and size (at least 64 cm^2) of the receptive field.

In the current study we found, that the movement of the centre of the receptive-field-area was smaller than 8 cm in 84.5 % of the cases with an average of 4.9 ± 4.8 cm and therefore not to be a challenge for the functionality of the Phantom Stimulator. Considering a simplified circular shape of the receptive fields of 117 cm^2 (rounded mean size of the detected fields), an overlap below 30 % would generate a movement of more than 8 cm of the centre of area. Therefore, we further consider an overlapping percentage of less than 30 % to be a challenge for the functionality of the Phantom Stimulator which was not the case in the current study.

In this study, the size of the receptive fields was significantly larger from the fourth meeting on compared to the first. This data does not yield any challenges for the functionality of the Phantom Stimulator as a receptive field growing in size will not compromise its overlap with the system's electrodes' position determined on the first day. A possible explanation for the increase in size of the receptive fields is possibly an increased self-awareness of the participants as most of them did not have any prior experience in the localization of their receptive fields. However, a steady increase over 31 days and therefore training effect contributing to the increased size of the receptive fields can be excluded as the detected positive change from meeting one levels off from meeting four to seven.

The same line of reasoning can be applied for the overlap in percent of the areas. In the present study, mean values showed an average overlap between different meetings of 54.3 ± 35 % which is still enough to ensure the functionality of the Phantom Stimulator. However, in 25 % of cases the overlap was < 30 % which needs to be considered for future application.

The extent of the observed movement is, as expected, relatively small. This, possibly as 31 days are a relatively short time-frame for large neuronal adaptations. For example, a reorganization of 10–14 mm in the somatosensory cortex of adult primates took longer than 12 years to occur (Pons et al., 1991). In any case, in face of the current findings, at least two meetings with full testing of the presence and size of the receptive fields are recommended since from day one to day two 15 additional receptive fields were mapped.

The evoked feelings in the phantom were described with the words prickling, stroking, pulsating or painful. Fundamental in this context is that the only negatively connoted word (painful) is present in merely 2.3 % of the detected receptive fields. Compared to the percentage of positively or neutrally connoted descriptions, this is a neglectable fraction and therefore does not compromise the ethically correct use of the Phantom Stimulator.

Table 4
Change in size of the receptive fields compared to meeting 1. Data is given as mean ± SD (standard deviation).

	Meeting 2	Meeting 3	Meeting 4	Meeting 5	Meeting 6	Meeting 7
Change (%)	34.3 ± 171.2	38.4 ± 130.5	217.1 ± 415.0	101.0 ± 205.2	271.5 ± 887.8	118.4 ± 268.7
p-value	.340	.122	.000	.010	.000	.006

Table 5
Overlap and movement of centre of area of the receptive fields compared to meeting 1.

	Meeting 3		Meeting 4		Meeting 7	
	Overlap (%)	Movement (cm)	Overlap (%)	Movement (cm)	Overlap (%)	Movement (cm)
Mean ± SD	44.8 ± 35.5	5.3 ± 5.4	47.2 ± 39.7	5.0 ± 3.2	54.3 ± 35.0	4.9 ± 4.8
95% Lower Confidence Level	36.1	4.1	37.0	4.2	44.9	3.9
95% Upper Confidence Level	53.4	6.4	57.4	5.7	63.6	6.0

Table 6
Comparison of the mean step width, swing and stance phase, self-selected walking speed as well as the phantom limb pain of the amputated leg during the functional (ON) and unfunctional (OFF) Phantom Stimulator situations. The Phantom limb pain was assessed by visual analogue scale ranging from 0-10. Note: SD = standard deviation. cm = centimetres. % = percent. m/s = metres per second.

	ON	OFF	p-Value
Step width (cm)	18.4 ± 2.7	18.7 ± 2.5	.219
Stance phase (%)	60.2 ± 3.6	59.9 ± 3.5	.030
Swing phase (%)	39.8 ± 3.6	40.1 ± 3.5	.021
Speed (m/s)	1.1 ± 0.2	1.1 ± 0.2	.367
Phantom limb pain	0.4 ± 1.3	0.3 ± 0.9	.59

4.2. Gait analysis

Comparing the obtained data to age-matched subjects without amputation, a slower self-selected gait speed and a larger step width can be seen in the present study compared to controls. Those controls had a mean walking speed of 1.3 ± 1.9 (male; (Himann et al., 1988)) and 1.5 ± 1.2 (female; (Kaneko et al., 1991)) m/s and a step width of 9.7 ± 3.0 (male) and 7.0 ± 3.5 (female) cm (Hollman et al., 2011). This, indicates a less secure gait of people with amputation and their prosthetic device compared to controls.

Self-selected gait speed and step width were not significantly different between electrical stimulation on and off conditions. However, a very small but significant difference in the percentage of the stance and swing phase of the prosthetic leg was observed with the electrical stimulation compared to placebo. An increased percentage of stance phase compared to swing phase generally shifts the gait pattern towards a two-legged symmetry, which is believed to be beneficial for secondary problems as for example osteoarthritis (Po-Fu Su et al., 2007). However, the difference is so small that it cannot be named clinically meaningful. Possibly, a larger difference might have been found with more challenging tasks, e.g. walking with obstacles, uneven surface, more turns or darkness. This, as amputees may rely more heavily on sensory feedback from receptive field stimulation when their other resources are temporarily removed, such as vision or cognitive attention (Barnett, Vanicek, and Polman, 2013; Howard, Perry, Chow, Wallace, and Stokic, 2017). Also, with a mean post-amputation time of 10.8 ± 10.7 years, participants were well trained and used to walking with their prosthetic device. Larger differences might also be seen in people with a trans-femoral amputation as this kind of amputation yields more coordinative challenges while handling the prosthetic device. Possibly, also a longer active use of the feedback system might enhance differences. Longer exposure duration must be aspired as changes in acquired gait pattern because of amputation might require more time than available in this study to take place. In this setting also limiting the research to subjects with shorter time since amputation might be a valuable alternative as their gait pattern is not yet as consolidated.

Phantom limb pain did not increase significantly with the use of the functional Phantom Stimulator compared to the placebo setting. Therefore, the use of the Phantom Stimulator, on people with a history of phantom pain, can be considered safe. If the Phantom Stimulator yields any positive effects on phantom pain could not be assessed through this study as none of the subjects reported suffering any acute episodes of phantom limb pain at the time of the gait analysis.

A critical point for the function of the Phantom Stimulator is that all 33.3 % of the tested participants having phantom sensations or phantom limb pain in the phantom foot itself had these feelings during both tested situations. A question that arises from this observation is whether the use of electrical impulses is necessary to obtain changes in gait parameters, phantom sensations and phantom limb pain, or if the simple use of pressure or touch of the receptive fields would be a large enough stimulation.

4.3. Limitations

The current investigation has several limitations: i) Participating subjects were relatively old as the testing protocol was rather time consuming which resulted in mainly retired persons or inpatients to volunteer; ii) Results may not hold true for different amputation levels since the study only included subjects with trans-tibial amputation; iii) the single-day assessment of electrical stimulation does not provide information of a potential effect when subjects were using the device for an extended period of time; iv) since the size and overlap of the receptive fields was assessed manually, it may be affected to a certain degree by daily fluctuation of the subject – tester interaction in addition to the 'objective' position of the centre of the area.

5. Conclusion

In conclusion, it can be said that no relevant changes of the receptive fields challenging the functionality of the Phantom Stimulator were detected within the time period of 31 days in people with a trans-tibial amputation. The small changes still allow the electrodes to stimulate the selected receptive field when they are placed in the same location over one month. Nevertheless, we suggest at least two meetings to assess which receptive fields are to be considered appropriate for the electrical stimulation. The Phantom Stimulator did not affect gait pattern, phantom sensations or phantom limb pain to a relevant degree and can, as such, likely be used without adverse effects.

Further studies should investigate chronic effects and side effects when the electrical stimulation is used on a daily basis, not only in persons with longer time since amputation but also in those with newly lost limb.

Conflicts of interest

The authors declare that they have no conflict of interest.

Compliance with ethical standards

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975 (in its most recently amended version). Informed consent was obtained from all patients included in the study.

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