**Supplementary Tables 1–4 for**

**BCI training to move a virtual hand reduces phantom limb pain: A randomized crossover trial**

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**Supplementary Table 1.** Phantom sensation for each patient

|  |  |
| --- | --- |
| ID | Phantom sensation |
| Pt 1 | His right hand was amputated due to an accident that occurred during his work, at which he controlled a milling machine. Phantom hand is located inside the stump. Previously, the phantom hand was located outside the stump without a forearm. The pain decreased gradually and was embedded in the stump. Usually, his phantom hand stays in a slightly open posture. He feels like his hand is embedded in cement, and it is a leaden pain. He also has sporadic pain. DREZotomy was not performed. He could move each finger of his phantom hand slightly. |
| Pt 2 | He has continuous pain around the ulnar side from his third finger and the ulnar side of his left forearm and upper arm as if it were being screwed in a vise. He also has a paroxysmal shooting pain, especially when the weather is bad. He feels like he is being touched on the fingertips of the phantom hand when he is touched on his left upper arm. He has not yet undergone DREZotomy. |
| Pt 3 | Patient experiences continuous pain from the fingertips to the forearm of his phantom limb, with particularly severe pain at the fingertips, finger joints, and wrist. The continuous pain is as if the hand were wedged in a door. After coagulation of DREZotomy, his shooting pain almost disappeared, although some continuous pain remains. He could slightly move his phantom hand to grasp and open. |
| Pt 4 | He was caught in a conveyor belt and cut his right upper limb. His phantom hand was closed at the beginning and has started to open a little after mirror therapy, although it is difficult to move the phantom hand. The phantom hand is positioned in the middle of the forearm. He experienced a telescoping phenomenon at the beginning, though the hand position does not change now. In addition to continuous pain, he experiences frequent attacks of sporadic pain. |
| Pt 5 | He feels a pins-and-needles pain in his left hand. Before DREZotomy, he had paroxysmal shooting pain as if his hand were being bitten by several dogs. He could slightly move his phantom hand, but not individual fingers. |
| Pt 6 | He has continuous pain on the palmar side of his left wrist and paroxysmal shooting pain on his left thumb and the palmar side of his left fifth finger. He has not yet undergone DREZotomy. |
| Pt 7 | He felt pain around his fifth finger as if it were being screwed by a vise. The pain lasted for a short time and recurred many times a day. The pain remains after DREZotomy. There is a constant pins-and-needles pain in his right hand. He could move his phantom hand almost like the intact hand. |
| Pt 8 | He has some tingling pain of NRS 3-4/10 across the whole back of his hand. A sporadic pain of NRS 9/10 attacks several times per hour. He cannot move his right hand at all. He has no sensation of his right hand. He has not yet undergone DREZotomy. |
| Pt 9 | He has strong pain from his fifth fingertip to his forearm of ulnar side with numbness. His pain consists of both continuous and sporadic pain. The pain intensity varies throughout the day with NRS from 1 to 7. He feels sporadic pain every 2**–**10 minutes. He has experienced mirror therapy training, although he was not able to continue the training without significant improvement of pain. |
| Pt 10 | He feels a pins-and-needles pain in his forearm. He experiences sporadic pain lasting 30 s to 1 min several times per day. Sometimes, he feels pain in his shoulder or chest. His right phantom hand stays in a frozen posture. |
| Pt 11 | The phantom limb shrinks to the middle of his left forearm, and the patient experiences pain in the thumb to the third finger of his phantom hand. The pain becomes worse when it is cold. Sometimes, he has a shooting pain in his phantom hand even after DREZotomy. He could slightly move the fingertips of his phantom hand. |
| Pt 12 | He has pain in his forearm as though he had put his arm in ice water. His phantom hand is frozen into the posture of an opening hand. He can exert force on the phantom hand but it makes the pain stronger. The dull pain on the ulnar side of the forearm becomes severe approaching the end of work in the evening. |

**Supplementary Table 2.** Subjective reports before and after trainings

|  |  |  |
| --- | --- | --- |
| ID | Task | Patient comments |
| Pt 1 | After real training on Day 1 | I felt numbness similar to the feeling after squatting. There is no pain. I feel like my phantom hand is not my hand, although it is my hand. My phantom hand is as it is. The pain is going away. Feeling like being anesthetized. There is no pain. |
| Before real training on Day 2 | Yesterday I got numb pain of NRS 3-4. I felt that the pain was suppressed more than usual. |
| After real training on Day 2 | I did not feel pain during the training. I felt only numbness. It was difficult to make the hand image grasp. It was more difficult in the latter half of the training. |
| Before real training on Day 3 | No particular changes. |
| After real training on Day 3 | I could make the hand image grasp better than the previous training, but there were still many cases when the hand image became open against my will. I felt no pain, only a feeling of numbness. |
| Pt 1 | Before random training on Day 1 | No particular changes after the previous trainings. |
| After random training on Day 1 | The hand image was controlled when I tried to move it doggedly. I could make the image open or close when I did it many times. It moves when I make an effort. The pain was eased. It does not hurt almost while I’m doing the training. I’m feeling only numbness even now. It’s about 3. It is a level 3 of numbness. Even with the same 3, it’s better. |
| Before random training on Day 2 | The pain is better than usual, although it’s rainy. |
| After random training on Day 2 | When I counted numbers on my phantom fingers, it opened and grasped. The image moved as I thought several times. My pain becomes better than before. |
| Before random training on Day 3 | No particular changes. |
| After random training on Day 3 | It was harder to move the image than I expected. The image moved when I repeated several times without putting much effort. Sometimes it moved as I thought, but mostly it did not move as I thought. Pain became a mild numbness. |
| Pt 2 | After random training on Day 1 | I could move the image more smoothly than last time. Pain was improved and became mild. |
| Before random training on Day 2 | No particular changes. |
| After random training on Day 2 | Pain became much lighter. The response of the image was improved. I feel that the movement will improve as the pain eases. |
| Before random training on Day 3 | No particular changes. |
| After random training on Day 3 | I could control the image well. I feel my hand becoming light. I feel sleepy. |
| Pt 2 | Before real training on Day 1 | No particular changes after the previous trainings. |
| After real training on Day 1 | The image moved smoothly. The numbness became even lighter. |
| Before real training on Day 2 | I could get the trick of moving the image yesterday. I could control it by moving the fingertip. The pain came back a couple hours after coming home, but the pain improved again when I made an image to move my phantom hand by myself. |
| After real training on Day 2 | It is almost the same as previous times; the pain becomes stable at a reduced state. |
| Before real training on Day 3 | Yesterday, the pain returned to usual after I came home. |
| After real training on Day 3 | What is left now is paralysis, although it is not numbness or a sense of tingling. The mobility of the phantom hand has not changed. The coldness of the phantom hand has become better. I could better control the image when I was conscious on the first joint. The current state is very easy for me. |
| Pt 3 | After real training on Day 1 | I could control the image better than at the beginning. In general, I could control the image as I intended when I moved the phantom hand with normal strength, but when I tried hard, it moved in the opposite direction. The pain became quite easy. |
| Before real training on Day 2 | The pain became bad last night due to rain. Yesterday’s training ended at 11 o’clock. The pain increased around 13:45 pm. I feel a tingling pain on the base of my right thumb. The pain became stronger at 5**–**6 at night. I could not sleep well. I feel pain stronger than usual. |
| After real training on Day 2 | Although the control does not go well, the pain becomes calm while it’s coming back a little bit. |
| Before real training on Day 3 | No particular changes. |
| After real training on Day 3 | The controllability remains as ever. Sometimes it works well, but sometimes not. The pain becomes much easier to manage. |
| Pt 3 | Before random training on Day 1 | No particular changes after the previous trainings. |
| After random training on Day 1 | I thought the success rate was about 30%. However, I could control the image by my thoughts without putting strength on the phantom hand. Especially, I could make the image open. The pain was at the best state we have ever had. |
| Before random training on Day 2 | No particular changes. |
| After random training on Day 2 | I think the controllability was the same. I could make it open but it was difficult to close. The pain became better when I concentrated on the task. |
| Before random training on Day 3 | I have pain at the base of my right thumb since last night. |
| After random training on Day 3 | This time was the worst of the three times. Even if I tried to open it, it closed. However, the pain was improved, and was reduced to 1/10. Even after the training, the pain remained at about 2/10 |
| Pt 4 | After real training on Day 1 | Pain became the easiest. The tearful pain disappeared. The pain runs when the hand image stopped moving. The pain became easier when the hand image opened. I could control the hand image as I thought. The phantom limb became warm. |
| Before real training on Day 2 | No particular changes |
| After real training on Day 2 | I could control it so-so. The pain is calm. The pain is not a tight pain like it used to be. I feel a little better. When I concentrated on the control, the pain was relieved. |
| Before real training on Day 3 | After yesterday’s training, my phantom limb remained in the posture of slightly opened hand. The pain was easy without being a strong pain. The feeling of the wrist of the phantom limb being tightened continues as usual. This is not a pain. This situation is comfortable. |
| After real training on Day 3 | I think I could control it well. The pain becomes calm. There was no strong pain. |
| Pt 4 | Before random training on Day 1 | I felt pain after the previous training, because it was cold. Recently, the pain improved because it was warmer. |
| After random training on Day 1 | This time, I felt some sporadic pain. I felt pain in the index finger and the little finger. The pain was stronger than the previous training. I had a pain when I imagined the phantom movements clearly. Although I did not feel pain so much during the previous training, I feel more pain in this time. Maybe I did imagine the hand too forcefully. |
| Before random training on Day 2 | No particular changes. |
| After random training on Day 2 | The situation did not change. Although the pain gradually decreases, it occasionally runs from the base of the finger. Now, I feel a tightening pain in my wrist. |
| Before random training on Day 3 | It was okay after yesterday’s training. |
| After random training on Day 3 | Pain is at its easiest now. The tightening pain in the wrist decreased. Although some sporadic pain runs occasionally, the frequency of the pain decreased. I could control the hand image well. |
| Pt 5 | After random training on Day 1 | It was difficult to move the image. Although I feel the hand image is my own hand, I could not control the image. The controllability did not change during the training. Also, pain did not change. |
| Before random training on Day 2 | No particular changes. |
| After random training on Day 2 | Again, it was difficult to control the image. I could not get the trick of it. The pain did not change. |
| Before random training on Day 3 | No particular changes. |
| After random trainings of Day 3 | It is still difficult to control the image. The hand did not move as I expected. The pain did not change. |
| Pt 5 | Before real training on Day 1 | The previous training was difficult. There were no particular changes after the previous trainings. |
| After real training on Day 1 | I could not close the hand image even once. I could not get the trick of it. |
| Before real training on Day 2 | No particular changes. |
| After real training on Day 2 | I think the controllability is as usual. It becomes more often closed, but even when I tried to close my phantom hand, the hand image opened. The pain did not change. |
| Before real training on Day 3 | No particular changes. |
| After real training on Day 3 | I could make the image grasp 3**–**4 times. I could get the trick of it a little. I could control the image 3**–**4 times when I concentrated on the task without putting too much force. The pain did not change. |
| Pt 6 | After real training on Day 1 | The pain suddenly down. The feeling of moving my phantom hand remains unchanged. I moved the phantom limb according to the movement of the hand image. So I did not intend to control the image. |
| Before real training on Day 2 | There was no pain for two hours after the training of yesterday, but it returned again after that. |
| After real training on Day 2 | Sometimes I could control the image, but sometimes not. I became better at controlling the image compared with the beginning. The pain improves. |
| Before real training on Day 3 | The pain was down until night when I slept. I had a pain when I went to bed. |
| After real training on Day 3 | It was difficult to control the image today. I could make the hand image move a little, but it did not move any further. I did not understand why I could not control it. The pain did not change. |
| Pt 6 | Before random training on Day 1 | Recently, I felt pain because the weather was bad. |
| After random training on Day 1 | I feel that I can gradually control it better, but it is still far from controllable. The pain gradually increases. |
| Before random training on Day 2 | I had more pain than usual after the training. It was difficult to sleep. I feel pain from morning today. |
| After random training on Day 2 | I got to be able to move it a bit. It worked just the opposite way. For example, when I intended to grasp, the image opened. Pain did not change much. |
| Before random training on Day 3 | There were no particular changes after the training. But it became very painful after around 3 o’clock this morning. |
| After random training on Day 3 | The pain decreases. I had a strong pain today, but now it has settled. It works well when I intended the opposite movements. I became able to control it well. |
| Pt 7 | After real training on Day 1 | I’m tired. I felt a numb pain in my arm. I feel that my pain decreased to a mild numbness. I could move it better around the later part of the training. |
| Before real training on Day 2 | No particular changes. |
| After real training on Day 2 | I could move the image so-so. The controllability was better than yesterday. I could control it smoothly today. The pain becomes a little lighter. |
| Before real training on Day 3 | I went to bed yesterday as soon as I came home. No significant changes. |
| After real training on Day 3 | It was difficult to move it during the last training. I think my pain becomes a little better. |
| Pt 7 | Before random training on Day 1 | The pain is as usual. |
| After random training on Day 1 | It was easy to grasp, but difficult to open. It was not so bad. The pain was relieved when I concentrated on the screen. |
| Before random training on Day 2 | I got tired yesterday. The pain did not change markedly. I felt pain with fatigue when I got home and went to bed yesterday. |
| After random training on Day 2 | Because I concentrated, I had less pain in my arm. |
| Before random training on Day 3 | I had a very strong pain last night. The pain is as usual this morning. |
| After random training on Day 3 | I could control it well. I felt my pain becoming light, because I concentrated on the task. |
| Pt 8 | After random training on Day 1 | It was difficult to control the image at the third training. I could do better even in the second training. The pain was similar. I feel pain at the base of my thumb. The pain becomes strong when I make an effort. |
| Before random training on Day 2 | No particular changes. |
| After random training on Day 2 | This time I moved my phantom hand according to the image. During the training, the pain became strong for a while, but it quickly decreased. |
| Before random training on Day 3 | I have strong pain today. |
| After random training on Day 3 | At the beginning of the training, I felt much pain. But the pain was relieved during the training. The pain becomes worse after the training. It was difficult to move the image at the end. |
| Pt 8 | Before real training on Day 1 | No particular changes after the previous trainings. |
| After real training on Day 1 | I could control the image when I relaxed my shoulder and put my strength in my arms. The pain becomes small. |
| Before real training on Day 2 | No particular changes. |
| After real training on Day 2 | It worked well when I put the force on my whole arm, especially around the shoulder. I could make the image open a little bit. But it did not open in the full range. It opened halfway. The pain was not so much. |
| Before real training on Day 3 | I went to bed yesterday as soon as I came home. The pain is not terrible. |
| After real training on Day 3 | I could control it better than before. When I did it all the time, I felt tired and pain in my arm. It worked well after I took a rest. Although I felt pain at the beginning, it gradually declined. |
| Pt 9 | After real training on Day 1 | I went to sleep during the training. What is so difficult? It did not move as I expected. Pain improves since I came here. |
| Before real training on Day 2 | No particular changes. |
| After real training on Day 2 | It is fun to move, but difficult if it does not move. It was difficult to get the trick of it. I found that it moved when a shooting pain attacked me. I could not understand the difference between controllable and uncontrollable trials. There is little pain now. Usually the shooting pain attacks me a lot more. |
| Before real training on Day 3 | It was as usual yesterday. The pain was small on the first day for some reason. I got the hang of moving the image little by little. Unlike mirror therapy, it’s fun because I do not move my left hand. I can concentrate on my right hand. I hope that I can continue to do this. |
| After real training on Day 3 | A shooting pain came in the second half. There was still unintended movement of the image. However, there were some times when I could grasp it by my intention. I feel more pain now because the shooting pain came during the training. |
| Pt 9 | Before random training on Day 1 | The pain was relieved for 3**–**4 days after the previous trainings, but it returned as usual. |
| After random training on Day 1 | I could control the image best during the first 10 minutes of the training. I had a hard time during the third training. I feel that I can control the image better than the previous (real training). |
| Before random training on Day 2 | I felt pain after yesterday’s training. |
| After random training on Day 2 | This time, the pain was always 0. It was easy to concentrate. I could control the image better in the previous trials. Usually the pain will never be 0. |
| Before random training on Day 3 | The pain was 0 until I left the hospital yesterday. The pain was around 2**–**3 for the day. The pain is as usual today. |
| After random training on Day 3 | My concentration was disturbed due to a shooting pain during the training. About half of the movements were unintended. I found the trick to strengthen the fingers. The hand image opened according to how I put the strength in the phantom fingers. |
| Pt 10 | After random training on Day 1 | I could control the image by moving only the little finger. I could forget the pain while I concentrated on the task. I remembered the pain after the training was over. |
| Before random training on Day 2 | Today, I have had pain since morning. |
| After random training on Day 2 | I just got the trick of it a little bit. I think the hand image opens when I do not think about anything. Pain becomes small enough to ignore. The cold feeling disappeared, although there is still some numbness. |
| Before random training on Day 3 | I felt pain yesterday, but it became better today. |
| After random training on Day 3 | I could not move well. I think that the feeling of moving the finger was important. I could forget the pain when I concentrated on the tasks. |
| Pt 10 | Before real training on Day 1 | No particular changes after the previous trainings. |
| After real training on Day 1 | I felt pain for a moment while I was moving my phantom hand. Still, it is difficult to grasp completely, although I could make it half way to grasping. I have been getting the trick of it better than the previous 3-day trainings. |
| Before real training on Day 2 | Today, I feel pain more than usual. |
| After real training on Day 2 | So far I exerted strength when I intended to grasp. When I opened the hand image, I just relaxed to loosen my grip. In this trial, I consciously tried to open it. But the image grasped. The pain was quite relieved, but some numbness remains. |
| Before real training on Day 3 | The pain became better in the evening after I came home yesterday. |
| After real training on Day 3 | I felt pain for several seconds at the beginning of the training for 10 minutes, but the pain did not continue after that. I did not feel the cold pain because my right hand as warm, but the numbness does not change much. Usually, the right hand never gets warm. It is still difficult to open the hand image. I know that the image will open when I relax, but I wanted to make it open by exertion to open the phantom hand. |
| Pt 11 | After random training on Day 1 | The hand images moved into the posture opposite to my thoughts. It was almost uncontrollable. My pain was calm. |
| Before random training on Day 2 | My pain was as usual yesterday. |
| After random training on Day 2 | I thought I could control the hand image better during the first half of the training period, but it becomes difficult in the later part of the training period. I felt pain partly during the training. When I felt pain, I opened my phantom hand. At that time, the hand image also opened. |
| Before random training on Day 3 | My pain was better yesterday. |
| After random training on Day 3 | I felt I could control the hand image rather frequently. It was pretty good. I was trying to keep my hand open for 3 seconds. I think I was able to keep the hand open for 3 seconds sometimes. I was also able to keep my hand closed similarly. I did better than previously. I felt stronger pain today. |
| Pt 11 | Before real training on Day 1 | No particular changes after the previous trainings. Recently, I feel more pain. |
| After real training on Day 1 | It was more difficult to open. Sometimes, I could make the image grasp according to my intentions. Sometimes, it was opposite to what I intended. I have no pain now, although I felt pain at the beginning. The pain gradually calmed down. |
| Before real training on Day 2 | No particular changes. |
| After real training on Day 2 | I could control the image surprisingly well at the end of the training. The hand image grasped faster than I intended to grasp. I could make the image open as I intended. There was no pain. |
| Before real training on Day 3 | No particular changes. |
| After real training on Day 3 | I could open the hand a little bit. I focused on opening the image this time. The hand image grasped independent of my intentions. I could move it almost as I intended, but it was difficult to make the movement complete. There was no pain. |
| Pt 12 | After real training on Day 1 | Somehow I could control the image. I got the trick of it. The pain is okay. |
| Before real training on Day 2 | The pain was relieved after the training yesterday. I even forgot to take my medicine at noon. I took medicine about 3 o’clock, but the pain came back around 10 o’clock. Now, the pain is about as usual. |
| After real training on Day 2 | I could do the task well. Today, the pain is entirely fine. |
| Before real training on Day 3 | I have pain today. It may be due to the rain today. I drank a lot of alcohol yesterday. |
| After real training on Day 3 | I could control it very well. I did not feel pain while I did the training. I felt pain after the training. My pain is as usual now. |
| Pt 12 | Before random training on Day 1 | Today, I feel strong pain. |
| After random training on Day 1 | I could do it well. I could control it as usual. The pain was somewhat relieved. |
| Before random training on Day 2 | No particular changes. |
| After random training on Day 2 | I could control the image well. The pain improved. |
| Before random training on Day 3 | No particular changes. |
| After random training on Day 3 | I could control it. The pain improved as before. |

**Supplementary Table 3.** VAS during Real training

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Day1 | | Day2 | | Day3 | |
| No. | Pre | Post | Pre | Post | Pre | Post |
| 1 | 36 | 18 | 20 | 10 | 13 | 16 |
| 2 | 26 | 6 | 25 | 3 | 8 | 4 |
| 3 | 43 | 5 | 39 | 12 | 34 | 8 |
| 4 | 86 | 59 | 60 | 49 | 57 | 52 |
| 5 | 27 | 31 | 24 | 29 | 23 | 28 |
| 6 | 83 | 23 | 71 | 13 | 48 | 26 |
| 7 | 59 | 50 | 61 | 51 | 61 | 56 |
| 8 | 30 | 10 | 11 | 10 | 5 | 21 |
| 9 | 26 | 8 | 18 | 5 | 14 | 26 |
| 10 | 16 | 6 | 29 | 14 | 10 | 12 |
| 11 | 37 | 3 | 5 | 6 | 7 | 7 |
| 12 | 75 | 25 | 46 | 6 | 38 | 42 |

**Supplementary Table 4.** VAS during Random training

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Day1 | | Day2 | | Day3 | |
| No. | Pre | Post | Pre | Post | Pre | Post |
| 1 | 31 | 21 | 33 | 32 | 23 | 24 |
| 2 | 27 | 5 | 19 | 3 | 21 | 2 |
| 3 | 30 | 9 | 25 | 8 | 42 | 9 |
| 4 | 71 | 50 | 69 | 49 | 56 | 51 |
| 5 | 26 | 26 | 26 | 29 | 24 | 28 |
| 6 | 66 | 80 | 57 | 54 | 86 | 22 |
| 7 | 53 | 53 | 60 | 57 | 58 | 54 |
| 8 | 25 | 8 | 5 | 11 | 36 | 32 |
| 9 | 37 | 6 | 49 | 0 | 7 | 17 |
| 10 | 12 | 13 | 20 | 11 | 8 | 6 |
| 11 | 17 | 5 | 6 | 4 | 7 | 15 |
| 12 | 44 | 26 | 39 | 25 | 21 | 30 |