Asynchrony in the rubber hand paradigm: Unexpected illusions following stroke

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The rubber hand paradigm (Botvinick & Cohen, 1998) elicits a striking multisensory illusion. The participant views a prosthetic hand being touched by the Examiner while the participant's own hand (hidden from view) receives synchronous touch from the Examiner. Because of the correspondence between what the participant sees and feels, most participants experience a compelling illusion. It may seem to the participant that the prosthetic hand is her own hand and that she is feeling touch at the location of the viewed prosthetic hand. When testing participants with the rubber hand paradigm, researchers typically use asynchronous stimulation as a control condition. With temporal mismatch between what the participant sees on the rubber hand and what the participant feels on her own hand, the rubber hand illusion is abolished. However, as we demonstrate, sensory impairments following stroke can lead to the participant experiencing the rubber hand illusion even when stimulation is asynchronous. This surprising finding will be of interest to researchers working on body awareness and representation, and clinicians treating patients with impaired sensation.

We assessed four right-hemisphere stroke patients who were undergoing rehabilitation at the Oxford Centre for Enablement. All patients had left-side hemiplegia and in the absence of visual feedback, they demonstrated tactile and proprioceptive impairments, including: detecting and localising light touch to the left hand; identifying objects placed in the left hand; identifying the precise location of the left hand. The assessment was primarily intended for training purposes, that is, testing various pieces of equipment for assessing sensation. Halfway through the session, and with the view of providing a bit of 'fun relief', we introduced the patients to the rubber hand paradigm. Stimulation was administered using a paintbrush with rigid bristles. Brushstrokes were firm to enable all four patients to detect stimulation, that is, stimulation was above each patient's threshold for detection. There were four trials, each lasting approximately 60 seconds: left-(contralesional)-hand synchronous; right-(ipsilesional)-hand synchronous; left-(contralesional)-hand asynchronous; right-(ipsilesional)-hand asynchronous. We invited the patient to describe the experience, during or following the trial, and we used one of Botvinick and Cohen's (1998) questionnaire items to gauge illusion strength. Following each trial, the patient was asked "to what extent do you agree with the statement: It seemed as if the rubber hand was my own left (or right) hand?" The patient responded using a seven-point visual analogue scale, ranging from 0 (not at all) to 6 (very strongly agree).

All patients reported a compelling rubber hand illusion during the left-hand-synchronous trial (P1 = 6, P2 = 5.5, P3 = 4, P4 = 6). In this trial, the patient viewed a prosthetic left hand being touched, while the patient's *affected* left hand (hidden from view) received synchronous touch. Two of the patients also experienced the rubber hand illusion, albeit weaker, during the right-hand-synchronous trial (P1 = 4.5, P2 = 4, P3 = 0, P4 = 0). This pattern – a stronger illusion for the contralesional hand compared with the ipsilesional hand – maps onto previous studies, and has been elicited across research programmes comprising diverse groups of stroke patients (Burin et al., 2015; van Stralen, van Zandvoort, Jaap Kappelle, & Dijkermann, 2013; Zeller, Gross, Bartsch, Johansen-Berg, & Classen, 2011). One explanation for this asymmetry is that, following stroke, the integration of contralesional afferent and efferent motor signals is disrupted. This leads to a weaker (and perhaps more flexible) sense of body ownership for the affected side, and the patient is more prone to contralesional body illusions (Burin et al.).

Our novel finding was for *asynchronous* stimulation. We expected the rubber hand illusion to be abolished, and indeed it was in the right-hand-asynchronous trial: all four patients provided illusion scores of zero, and three of the patients commented on the asynchrony. Surprisingly, in the left-hand-asynchronous trial, three patients experienced the illusion (P1 = 6, P2 = 5, P3 = 3, P4 = 0). Two patients did not detect the asynchrony, which is interesting in itself, and the third patient detected the asynchrony but nonetheless experienced the rubber hand illusion. He said "I tried to understand it, and it seemed [just] like after the stroke, when I saw my hand being touched and it took a while to feel the touch". The experience of an asynchronous illusion has been shown in a previous case study (see van Stralen et al., 2013). This right-hemisphere stroke patient, who was recovering from somatoparaphrenia (a delusion in which she denied left-hand ownership), demonstrated a strong contralesional rubber hand illusion for both synchronous and asynchronous stimulation[i]. The researchers attributed this to the patient's profoundly disturbed body image. But somatoparaphrenia may not be the only explanation, given that three of our four patients experienced an asynchronous illusion, despite not having delusions of body ownership. In contrast, Burin et al. (2015) did not find that asynchronous stimulation resulted in the rubber hand illusion with their

patients, but these patients were selected on the basis of having intact sensation. This leads us to believe that the experience of the rubber hand illusion with asynchronous stimulation may be directly related to sensory impairments. We note here that Zeller et al. (2011), with patients most like our own, did not test asynchronous stimulation.

We put forward three hypotheses for our patients' experience of an asynchronous rubber hand illusion. First, stroke may have affected the patient's ability to detect and integrate synchrony. This hypothesis aligns with the subjective report of two of our patients, who confessed not to notice that stimulation of the left hand was asynchronous. It is also consistent with findings from other studies. Individuals with Parkinson's disease (Ding et al., 2017) and individuals with schizophrenia and passivity symptoms (Graham, Martin-Iverson, Holmes, Jablensky, & Waters, 2014) show reduced sensitivity to asynchronous stimulation in the rubber hand paradigm. Difficulties detecting asynchrony – perhaps due to impairments with temporal processing of sensory information (Ding et al.) or internal timing mechanisms (Graham et al.) – have been postulated. Neurologically healthy individuals also differ in their sensitivity to perceiving asynchrony, and this sensitivity correlates with susceptibility to the rubber hand illusion (Costantini et al., 2016). Second, stroke may have affected the patient's processing speed for somatosensory signals. Thus it was not only more difficult for the patient to detect asynchrony but the experience of asynchrony did not cue the patient to the fact that the viewed hand did not belong to him because, in his everyday activities, somatosensory signals were slowed in comparison to visual signals. This hypothesis fits with the subjective report of one patient, who remarked upon the familiarity of the experience, drawing parallels with his post-stroke experience of seeing his body being touched and feeling the corresponding sensation with a delay. We imagine that this sensory mismatch may have led to a feeling of detachment from the body. Individuals with depersonalisation and derealisation also describe the feeling of being an outside observer on their own body, and this sense of separation from the body has been partly attributed to failures of multisensory integration. Interestingly, Rabellino et al. (2016) have recently shown that individuals who have post-traumatic stress disorder, with depersonalisation and derealisation symptoms, are prone to experiencing an asynchronous rubber hand illusion. Third, stroke may have affected the patient's allocation of attention under conditions of multisensory stimulation. According to Titchener's law of prior entry, "the object of attention comes to consciousness more quickly than the objects which we are not attending to" (Titchener, 1908, p. 251). If the patient preferentially allocates attention to the visual modality, tactile signals may become conscious but with a delay, such that asynchrony is less apparent. Each of our three hypotheses are speculative, and our sample comprises only right-hemisphere stroke patients. We therefore hope that our postcard observation inspires systematic investigation of the visual rubber hand paradigm and synchrony in both right- and left-hemisphere stroke patients, and that it inspires discussion about possible impairments of multisensory integration in the post-stroke recovery phase.

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[i] Note that simply looking at the prosthetic hand was sufficient to elicit feelings of ownership in van Stralen et al.'s (2013) patient. Unfortunately, we did not ask our patients whether looking at the hand resulted in an illusion of ownership, but recent data collected by Martinaud, Besharati, Jenkinson and Fotopoulou (2017) is informative on this point. The researchers tested 31 right-hemisphere stroke patients, and the majority experienced an illusion of ownership within 15 seconds of merely looking at the prosthetic left hand (see also Fotopoulou et al., 2008).