Abstract. For this experiment a visual illusion was created in which the participant's finger looked and felt as though it was being stretched to twice its normal length until it snapped and the tip came off. It was then stabbed with virtual weapons while skin conductance was measured. Sometimes the fingertip moved under the participant's own control and sometimes it moved independently. Curiously, detaching the tip of the finger destroyed the underlying ownership for the remaining stump as well as for the tip itself, even when the tip was under participants' control. These results have implications for theories of agency, embodiment, and tool-use.

Since the discovery that the peripersonal space of monkeys can be modified following tool use (Iriki et al 1996), several researchers have attempted to produce similar results in humans. Recent work by Kao and Goodale (2009) suggests that tools, when under our direct control, can be incorporated, or embodied, into the body schema. Embodiment relies, in part, on whether there exists an underlying sense of ownership (that an object or body part belongs to you), and a sense of agency (that we are the cause of our own actions). Agency may not be a necessary condition for embodiment (rubber hands can be embodied without moving), but perceived non-agency prevents embodiment (Newport et al 2010) while perceived agency enhances it (Tsakiris et al 2006). Importantly, when we use tools, we have a sense of agency over them: they move as we intend and we can predict the sensory outcome of goal-directed tool-based actions.

Uncertainty exists as to whether a tool extends peripersonal space or the tool is incorporated into the body schema, or even whether these two are distinct processes (Holmes et al 2007). Embodiment is frequently investigated with rubber hands or tools, but rubber hands, while looking like hands, rarely move under our control, and tools, while under our control, rarely look like hands. Even prostheses, which may or may not be tools, but often look like hands, rarely move like a real hand. Cardinali et al (2009) suggest that the way to distinguish body schema from peripersonal space is to manipulate visual or physical continuity because this is required to induce changes in the body schema, but not peripersonal space. A useful approach, therefore, might be to treat the hands themselves as tools and to artificially extend and detach them so as to include areas not previously within reach. Thus, detaching the fingertip and retaining causal links between the actions and consequences (ie agency) should modify peripersonal space, but not body schema while detaching the tip, but disrupting agency should modify neither. Alternatively, identical effects for both agency conditions might provide evidence for a shift in multisensory attention (Holmes et al 2007).

Modern technology allows for a variety of interesting bodily illusions, such as the experience of supernumerary limbs (Newport et al 2010) and the current experiment utilised such a system to manipulate vision, touch, and proprioception in order to create the illusion that the index finger of the participant had been stretched to the point that the tip had become detached. The MIRAGE system consists of an arrangement of cameras and mirrors such that participants can view live video images of their own hand in the same physical location as their actual hand. Because the software
and hardware combination can present digitally altered images within 20 ms, this system allows the online modification of the visual properties of the hand in real time. Twelve participants placed their extended arm into MIRAGE and viewed their hand as they tapped a block with their index finger. After one minute, they were asked a series of questions related to hand ownership and reality, rating the reality of the hand as 7.5/10 (mean) and ownership as (7.8/10). The high ownership ratings can be attributed to the high degree of visual, spatial, tactile, and motor correspondence with their own hand.

Participants then underwent four conditions in an order counterbalanced between participants: attached agency (AA), attached no agency (AN), detached agency (DA), and detached no agency (DN). For AA, participants viewed their hand tapping the block for a further minute before being ‘stabbed’ by a virtual weapon (three times each to the tip and stump in a pseudorandom order) while skin conductance (SCR) was measured. SCR is a valuable, implicit indicator of embodiment: threatening an embodied fake limb produces a similar response to threatening the real limb (Ehrsson et al 2007), and threat can also increase the sense of embodiment (Giummarra et al 2010). The virtual weapons were a hypodermic needle or a kebab stick held by the experimenter and stabbed from the side towards the protruding finger. In reality, these were pre-recorded images of the experimenter holding the weapon that approached with a bell-shaped velocity profile, reversing direction within 5 mm of the finger while at a velocity of 450 mm s$^{-1}$. For AN, the tapping finger moved out of synchrony with the real hand by introducing a 500 ms delay to the viewed image. For DA, the experimenter gently pulled the fingertip while at the same time the image of the finger was stretched so that the impression for the participant was that his/her finger was being stretched to twice its normal length and able to touch a wooden block that was previously out of reach. In order to remove the continuity of the finger and tip, when the finger neared double length, the tip suddenly became detached and the stretched portions sprang back so that the finger appeared to stretch and then break. The tip was then moved slightly to one side and a block inserted between the tip and stump as a final ‘convincer’ (figure 1). For DA, the tip moved in time with the participant’s own movements and for DN a delay was introduced for the tip, but not the stump. After 1 min of tapping, the block was removed and the finger was stabbed as in the other conditions. The experiment was conducted in accordance with local ethics and the World Medical Association Helsinki Declaration as revised in October 2008.

![Figure 1.](image)

Figure 1. Experimental setup showing: (top) tapping, pulling, stretching, and detaching; (bottom) the visual convincer, detached tapping, and stump/tip stabbing. The fingertip moved either synchronously or asynchronously with the stump.
High SCR for the fingertip in DA, but not DN would support a distinction between body schema and peripersonal space; high SCR for neither would suggest that continuity is vital for both and high SCR for both DA and DN would support an attention account. A $4 \times 2$ (condition $\times$ stab site) ANOVA revealed only a main effect of condition ($F_{3,33} = 5.27, p < 0.05$). Mean peak SCRs (figure 2) were highest for the AA condition and significantly reduced for AN—supporting the idea that a lack of agency can disrupt embodiment. SCR was also reduced for the DN fingertip, for which the tip was both detached and without agency. Rather surprisingly, SCR also remained low for the stump (still attached with agency).

Furthermore, and contrary to our expectations, the same effect was observed for DA, in which the stump and the tip, despite being detached, retained agency. Thus, agency over a remote body part does not appear to be sufficient for embodiment. Not only did detaching the finger prevent its embodiment, it also disembodied the remaining stump and hand.

Detaching the finger prevented the extension of peripersonal space and disrupted embodiment of the hand completely. Continuity may be vital for extending peripersonal space and/or incorporating tools into body schema. While the current paradigm was unable to distinguish between incorporation into the body schema and extension of peripersonal space, the methodology employed provides the potential for doing so.

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