

'Action binding': dynamic interactions between vision and touch

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To execute goal-directed movements accurately, it is necessary that sensory signals be transformed into appropriate motor command signals. This is commonly referred to as the 'sensorimotor transformation' problem and remains one of the most important and yet least understood issues in motor control research. Recent electrophysiological^{1,2} and neuropsychological^{3,4} reports suggest that there is no single, supramodal map of space that is used to guide movements. Instead, movements appear to be planned and controlled within multiple coordinate systems, each one attached to a different body part.

A critical and largely unresolved aspect of this 'sensorimotor transformation' problem is to understand how different kinds of sensory signals are integrated to provide an accurate representation of the body (the 'body schema'). This computation is made complex for several reasons. Throughout each day we are constantly moving. Movements can be relatively small, such as when we move our eyes while reading, or they can be large – for example, when we run to catch a bus. Nevertheless the mechanisms that compute and maintain our body schema must constantly track all such changes to provide an accurate representation of the relative positions of our body parts.

Our body schema must also be sufficiently flexible to deal with variations in the physical characteristics of our body. Such changes can be relatively long lasting, for example, as the result of normal ageing or if we are unfortunate enough to suffer an injury, or they may be relatively short-term such as the increase in weight and length of one arm when we pick up a hammer. Several recent studies serve to illustrate the dynamic and task-dependent nature of these bodily representations.

Electrophysiological investigations in monkeys reveal that regions of extrapersonal space that are within reaching distance (peripersonal space) are represented in many areas of the brain as integrated somatosensory–visual maps¹. In such maps, the visual receptive fields of bimodal (visual–tactile) cells can extend out

from the body surface into adjacent regions of peripersonal space: in cases where the tactile receptive field is located upon the arm, the visual receptive field can move with the arm when it is repositioned within the workspace¹. Such cells appear, therefore, to code the spatial position of visual stimuli within arm-centred coordinates. Two recent neuropsychological reports illustrate how our representation of peripersonal space can be rapidly and dynamically reconfigured when we hold a hand-held tool^{5,6}.

Farne and Ladavas⁵ studied crossmodal extinction in several right-handed neurological patients who were recovering from right-hemisphere strokes and presented with left-sided tactile extinction. That is, if a single tactile stimulus was presented to their left hand the patients could detect it. However, if the left-hand stimulus was accompanied by a tactile stimulus delivered to the right hand, then they would tend to report feeling only the stimulus presented on the right. In this study, patients sat at a table, maintaining central fixation, with their left hand placed palm down on the table surface but occluded from view by a cardboard shield, and their right hand holding a 38 cm long rake. Crossmodal extinction was investigated by presenting a tactile stimulus to the left hand and a visual stimulus on the right, close to the far end of the rake. After baseline levels of crossmodal extinction had been established, the patients completed a short period of reaching, during which they were required to reach with the rake to objects presented radially around the right shoulder outside the normal reaching distance. Crossmodal extinction was then re-assessed, immediately after the reaching period and then again after a short delay. The key finding from this study was that crossmodal extinction was shown to increase significantly (relative to baseline levels) immediately after reaching with the rake, but to return to baseline levels after a short delay. The authors interpret this finding as evidence that peripersonal space is re-mapped following tool use to include those areas of extrapersonal space that can be reached using the hand-held tool. This

result suggests therefore that the spatial extent of peripersonal space is not fixed, but can be dynamically and rapidly re-calibrated in a task-dependent manner.

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A similar result was obtained in an independent, single-case study of crossmodal extinction reported by Maravita *et al.*⁶ Their patient, 'BV', presented with left-sided tactile extinction following a right-hemisphere stroke. Maravita *et al.* also studied how levels of crossmodal (visual–tactile) extinction were modified when BV held a stick in his right hand which extended beyond normal reaching distance into extrapersonal space. They showed that when their patient held a stick that extended into far space, tactile extinction – as indicated by errors in detecting a tactile stimulus delivered to the left hand – increased significantly compared with trials where there was no stick, or in which the stick was present but was not held by the patient. An important difference between this finding and that reported by Farne and Ladavas⁵ is that BV never actively used the stick as a tool to retrieve far objects. This suggests that simply holding an object, which is capable of being used as a tool for reaching, can be sufficient to bring about a temporary modification (extension) of peripersonal space.

Further evidence for the dynamic and flexible nature of the visual–tactile interactions used to encode our body space comes from a psychophysical investigation reported by Kennett *et al.*⁷ These authors measured two-point discrimination thresholds for tactile stimuli delivered to the left forearm of their neurologically normal subjects, and manipulated vision of this arm. They measured two-point tactile discrimination thresholds under three conditions: when the subject could *not* view the stimulated arm (note that the stimulators could never be seen in any condition); when the subject could view the stimulated arm; and, when the subject viewed the stimulated arm through a magnifying glass.

Gaze-direction was held constant throughout. Their results indicated that tactile acuity is increased when subjects can view their stimulated arm, perhaps an unsurprising finding given recent neuropsychological reports⁸. What was more surprising, and of greater theoretical interest, was the intriguing finding that somatosensory acuity was improved still further by viewing the stimulated limb through a magnifying glass. That is, subjects became 'super-sensitive' to tactile stimulation when the visual representation of the arm was enlarged beyond normal scale.

The three studies outlined above illustrate how visual and somatosensory information can be rapidly and dynamically bound together to produce a task-dependent representation of peripersonal space (i.e. 'action binding'). But are there limits to the flexibility of these action bindings? A recently published report by Tipper *et al.*⁹ suggests that there are. This is an extension to their earlier paper¹⁰, in which they demonstrated independent effects of vision on somatosensation by showing that vision of the stimulated hand, without proprioceptive orienting of eye and head to that site, can enhance a subject's ability to detect tactile stimulation. In their follow-up study Tipper

*et al.*⁹ investigated whether a similar effect was obtained when the area of the body being stimulated was one that could not ordinarily be viewed. To investigate this, they compared tactile stimulation of the hand with tactile stimulation of the back of the neck and found that, although they could replicate their earlier finding – that sensitivity to tactile stimulation of the hand was increased by vision of the hand – they could not obtain a similar result for tactile stimulation delivered to the back of the neck. This finding suggests that rapid 'action binding' between vision and touch might be limited to body parts that are habitually viewed (e.g. the arm) and to situations that are frequently experienced (e.g. acting upon the world using a hand-held tool).

In conclusion, many questions remain unanswered with respect to how different kinds of sensory signals are integrated to provide an accurate representation of the body. However, behavioural findings in healthy and brain-damaged humans, together with electrophysiological studies in monkeys, are beginning to shed new light on how the brain dynamically binds together visual and somatosensory signals to create a task-dependent representation of peripersonal space.

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Meeting Report

Thinking Beyond the Fringe

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The 23rd Annual Conference of the Cognitive Science Society was held at Edinburgh, Scotland, UK from 1–4 August 2001.

In early August each year, Edinburgh in Scotland plays host to the Fringe Festival – the alternative answer to the city's traditional Arts Festival. This year, along with the jazz artists, theatrical groups and improvised performances, the city saw the 23rd Annual Conference of the Cognitive Science Society. On this, the first time that the conference has been held outside North America, the stated aim of the conference organizers was to facilitate the reunification of the multiple facets of the discipline of cognitive science. This aim was admirably fulfilled.

The conference was dedicated to the memory of the late Herbert A. Simon, who died in February at the age of 84. Simon

was the winner of the 1978 Nobel Prize in Economics and was widely recognized for his pioneering work in cognitive psychology and computer science. Friday morning was devoted to a symposium in his honour. The symposium was organized around presentations given by three colleagues of Simon's, Pat Langley (Stanford University, Stanford, CA, USA), Fernand Gobet (University of Nottingham, Nottingham, UK) and Kevin Gluck (Air Force Research Laboratory, Mesa, AZ, USA). They presented work performed in collaboration with Simon on issues as diverse as the heuristics of human problem solving, the key phenomena in expertise and the process of categorization. The talks were followed by 'Herb Simon stories' from the audience, each of which illustrated the immense respect and affection in which Simon was held.

Another highlight of the conference was the 2001 Rumelhart Award Prizewinner's lecture by Geoffrey E. Hinton (Gatsby Computational Neuroscience Unit, London, UK) on the topic of 'Designing generative models to make perception easy'. This is the first year that the Rumelhart prize, for contributions to the formal analysis of human cognition, has been awarded. Hinton was one of the researchers who introduced the back-propagation algorithm for the training of neural networks. His other contributions to neural-network research include Boltzmann machines, distributed representations, time-delay neural nets, mixtures of experts, and Helmholtz machines.

Hinton's lecture incorporated his latest research results, some of which were less than a week old. Starting from the assumption that the brain has a