TWO ROUTES TO ACTION IN THE HEALTHY AND DAMAGED BRAIN

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I. Limb apraxia

- Deficits in skilled action not attributable to weakness or incoordination; in particular, there are spatiotemporal errors in pantomimed tool use, actual tool use, imitation, as well as impaired action recognition.
- Occurs in approximately 50% of left hemisphere stroke.
- Much historical confusion about terminology (e.g., ideational versus ideomotor), characteristics, and neuroanatomic substrates.
- Classically, ideational apraxia was understood as a loss in the "idea" of the action, and ideomotor apraxia as a disconnection between an intact "idea" and motor output, but in practice these concepts have been extremely difficult to operationalize.

II. Brain regions critical for different components of skilled action (and for apraxia subtypes)

- One way to reduce the confusion is to eschew these classical labels and describe the neuroanatomic regions associated with *components* of the apraxia syndrome.
- Example: Buxbaum, Shapiro, & Coslett (2014) showed that the left posterior temporal lobe is critical for pantomime to the sight of tools, posterior temporal lobe plus frontal and parietal critical for imitation of meaningful tool-related movements, and frontal and parietal critical for imitation of meaningless movements.
- Tarhan, Watson, & Buxbaum (2015) showed that the same posterior middle temporal region is critical for action recognition.
- These and other data indicate that the posterior temporal lobe maintains tool-specific representations of the postures and movements associated with tool use, whereas supramarginal gyrus, S1, and M1 are critical for positioning the body in space over time.
- Lesions to these two loci give the flavor of ideational versus ideomotor apraxia. However, since both regions may be damaged by middle cerebral artery strokes, these components often co-occur.

III. The brain's two cortical action systems: The "2AS"model

- An informative "double dissociation" sheds light on two cortical action systems in the human brain:
- Apraxics with left posterior temporal/inferior parietal damage are unable to pantomime, and perform somewhat better (though still abnormally) with a tool in hand. However, they perform *normally* when reaching to and grasping objects (Buxbaum, Johnson, & Bartlett-Williams, 2005).
- This is the inverse pattern to that demonstrated by patients with optic ataxia, a disorder of visually-guided action seen after bilateral superior parietal lesions. Optic ataxics have no difficulty with pantomime or tool use, but perform abnormally in reaching and grasping (Karnath & Perenin, 2005).

- This double dissociation suggests that there are two cortical action systems: A bilateral dorso-dorsal stream for *moving* objects, and a left-lateralized ventro-dorsal stream for *using* objects (see Buxbaum & Kalenine, 2010; Binkofski & Buxbaum, 2013; Rizzolatti & Mattelli, 2003). This is the **Two Action Systems (2AS)** model.
- With damage to the *use* system, apraxics are abnormally reliant on visual feedback, and are deficient in body-relative movements, while remaining unimpaired in object-relative movements (Jax, Buxbaum, & Moll, 2006).
- They are also overly dependent on the visible structure of objects (size and shape). When visible structure does not cue an appropriate *use* action, or when visible structure conflicts with an appropriate *use* action, apraxic errors result (Watson & Buxbaum, 2015).

IV. The "Two Action System Plus" Model

- Conflicting actions are present in most situations in daily life.
- The ability to perform the correct action at the correct time requires a system for action selection based on current goals.
- The **Two Action System Plus (2AS+)** model includes a mechanism for accumulation of multiple potential actions in the supramarginal gyrus, and interaction with prefrontal control systems that bias competition based on task goals (see Cisek & Kalaska, 2010; Watson & Buxbaum, 2015).

V. Implications for relearning and rehabilitation

- Loss of the posterior temporal visuospatial component or disconnection between this component and the sensorimotor parietal component suggests the merit of strengthening connections between gesture representation and other aspects of semantic tool knowledge.
- Prior treatment studies in the aphasia domain using a "network strengthening" approach have proven successful (Boyle & Coelho, 1995).
- A study currently underway in our lab is assessing network strengthening as a treatment for limb apraxia.

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