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Tool-use and the left hemisphere: What is lost in ideomotor apraxia?

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ABSTRACT

Impaired tool related action in ideomotor apraxia is normally ascribed to loss of sensorimotor memories for habitual actions (engrams), but this account has not been tested against a hypothesis of a general deficit in representation of hand-object spatial relationships. Rapid reaching for familiar tools was compared with reaching for abstract objects in apraxic patients ($N = 9$) and in a control group with right hemisphere posterior stroke. The apraxic patients alone showed an impairment in rotating the wrist to correctly grasp an inverted tool but not when inverting the hand to avoid a barrier and grasp an abstract object, and the severity of the impairment in tool reaching correlated with pantomime of tool-use. A second experiment with two apraxic patients tested whether barrier avoidance was simply less spatially demanding than reaching for a tool. However, the patient with damage limited to the inferior parietal lobe still showed a selective problem for tools. These results demonstrate that some apraxic patients are selectively impaired in their interaction with familiar tools, and this cannot be explained by the demands of the task on postural or spatial representation. However, traditional engram theory cannot account for associated problems with imitation of novel actions nor the absence of any correlated deficit in recognition of the methods of grasp of common tools. A revised theory is presented which follows the dorsal and ventral streams model (Milner & Goodale, 2008) and proposes preservation of motor control by the dorsal stream but impaired modulating input to it from the conceptual systems of the left temporal lobe.

1. Introduction

Ideomotor apraxia (IMA) is a common disorder of complex action strongly associated with left hemisphere damage, especially damage to the left inferior parietal lobe (Buxbaum, Kyle, Grossman, & Coslett, 2007; Weiss, Rahbari, Hesse, & Fink, 2008). Exact definitions vary, but an agreed core feature is an inability to imitate or produce gesture to verbal command despite normal strength and sensation in the limb. This typically includes a clear abnormality when attempting to demonstrate tool-use by pantomime, and a milder impairment with the tool actually in the hand (Goldenberg & Hagmann, 1998; Sunderland & Shinner, 2007). The traditional explanation which has entered the textbooks is that these impairments arise from damage or impaired access to stored representations of the actions associated with specific tools (Buxbaum et al., 2007; Greene & Bone, 2007; Heilman, Rothi, & Valenstein, 1982; Poizner et al., 1995). Buxbaum and Kalenine (2010) provided an up-dated version of this account fitted within the framework of the dorsal and ventral streams model of action and perception. However, their account is still consistent with the traditional explanation in suggesting that what is lost in IMA concerns memories of actions associated with tools, or as they put it "sensorimotor information about skilled object use" (p203).

A difficulty for this action representation account is that most patients with IMA have difficulty not only with familiar tools but also with actions which do not require recall of motor memories, such as imitation of meaningless gestures or manipulation of novel objects. For example, most apraxic patients are impaired on the Kimura Box (Kimura, 1977; Sunderland & Sluman, 2000) which requires them to imitate manipulation of three novel objects. The most frequent response in defence of the representational account has been to suggest that these problems with novel objects or meaningless gestures have separate origins, and that their co-occurrence with impaired performance is a result of anatomical proximity of areas sub-serving different functions (Buxbaum et al., 2007). In support of this argument, rare cases with selective impairment for tool pantomime but not meaningless gesture imitation have been reported to occur under certain test conditions (Tessari, Canessa, Ukmar, & Rumiati, 2007). However, the rarity of such dissociations calls into question the adequacy of the action representation theory as an explanation for all cases of impaired tool use.

Sunderland and Sluman (2000) argued that a plausible alternative explanation for the majority of cases with combined problems in tool-use and manipulation of novel objects was impaired repre-

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sentation of body posture. They observed that the most evident problem during both tool-use and novel object manipulation was incorrect hand posture, for example using an abnormal and clumsy grasp when using a spoon. This contrasted with normal grasp on other tests of manual dexterity where there was less scope for variation in configuration of the hand. Sunderland & Sluman therefore concluded that there was an inability to form a model of current hand configuration as it grasped an object. A related account has been put forward by Goldenberg (1999), Goldenberg (2009) who suggested that in cases of IMA after parietal damage, inability to imitate meaningless gesture and problems with tools are both due to a difficulty in conceptualisation of spatial relationships – either between body-parts in the case of gesture imitation, or between the hand, tool and object it acts on. This model of spatial relationships is said to be in the form of descriptions of the juxtaposition of body parts, tool and environment. This is in sharp contrast to the deficit in motor memory or "visuokinesthetic motor engrams" proposed by the traditional theory of IMA (Heilman et al., 1982) and, argued Goldenberg, much more consistent with current models of the parietal lobes as centres for working memory and spatial representation.

A prediction arising from this alternative account is that apraxic patients should be impaired not just when manipulating familiar tools but also on tasks which demand representation of the spatial relationship between the hand and unfamiliar or abstract objects. In the first experiment in this paper we therefore contrasted tool grasping with grasping abstract objects of similar dimensions. Previously published data from four apraxic patients (Sunderland, Wilkins, & Dineen, 2011) was combined with data from additional apraxic patients and a comparison made with patients with posterior right hemisphere damage and normal controls. Tools were presented so that inversion of the hand was sometimes required if they were to be grasped appropriately for use, and this was contrasted with a condition where abstract objects were placed near to a barrier so that hand inversion was required for a comfortable grasp. In a second experiment with two patients we added another condition in which abstract objects had to be grasped appropriately to carry out a future action. For both experiments, the prediction under the spatial–postural theory was that apraxic patients would fail to invert the hand to grasp both tools and abstract objects, because both tasks required apprehension of object-hand relationships. In contrast the prediction from action representation theory was that apraxic patients would show a selective problem when grasping tools.

2. Experiment One

2.1. Methods and materials

Approval for the project was given by the Regional Medical Ethical Committee and written consent was obtained from participants consistent with the Declaration of Helsinki.

2.1.1. Participants

Stroke wards and community rehabilitation services were screened to identify patients with left hemisphere damage and evidence of apraxia on a brief Action Imitation Test (wave goodbye and copy a meaningless hand-on-chin gesture). Patients were selected for the study if a further detailed assessment at 3 months or more after stroke confirmed the presence of apraxia but normal performance on tests of line and star cancellation (Wilson, Cockburn, & Halligan 1987). Ten patients met these inclusion criteria and were recruited to the study. One patient proved unable to complete the reaching task and his data were excluded. A comparison group of 9 right hemisphere patients who were unimpaired on the apraxia tests but made two or more left sided omissions on the cancellation tasks were recruited from similar sources. All patients were formerly right-handed and had varying degrees of contralesional weakness and/or sensory loss (clinically assessed). All tasks requiring motor responses were therefore completed using the ipsilateral hand. Twenty right-handed normal controls of similar age and with no history of neurological disease, were recruited from patients' relatives and community groups. Half of these used their left hand for the motor tasks and half used their right hand.

Demographic details and scores on background measures for all participants are shown in Table 1. There were no significant differences between the four groups in age (Kruskal Wallis test, Chi-Square = 1.26, df = 3, NS) and the patient groups did not did differ significantly in time since stroke (Mann–Whitney test, $U = 33$, NS).

In addition to cancellation tests, the background measures comprised the Object Decision test of object recognition (Warrington & James, 1999), the Graded Naming test (McKenna & Warrington, 1983), and the Token Test of language comprehension (Boller & Vignolo, 1966). All the apraxic patients had some degree of dysphasia, varying from mild to moderate in eight cases. There was one case of severe global aphasia (Token Test Part One = 1/10; Graded Naming Test = 2/30).

2.1.2. Neuroimaging

Neuroimaging dating from the time of, or following, the index stroke was available for 8 out of 9 left hemisphere apraxic patients and for all 9 right hemisphere patients. One apraxic patient had only computed tomography (CT) of the brain, the remaining 16 having either magnetic resonance imaging (MRI) of the brain alone or in addition to CT. Eight patients had a dedicated research MRI performed, and in the remaining cases the clinical neuroimages were obtained for further analysis in accordance with the ethically-approved protocol. The findings of the neuroimaging for the two patient groups are summarised in Table 2. To allow a better understanding of the spatial distribution of lesions in the two groups, lesion distribution maps were created as follows. For MRI scans which included a T1-weighted 3D volume acquisition such as an MPRAGE (all of the research scans and 4 of the clinical scans) this sequence was used for the lesion mapping, otherwise the axial T2-weighted image was used. For the single patient with CT only, this image was used. Lesion masks were drawn manually using FSLVIEW by an experienced clinical neuroradiologist. The MPRAGE or T2-weighted image and lesion mask were co-registered to a 1 mm MNI152 template using FLIRT (Jenkinson & Smith, 2001). For each group, the individual coregistered lesion masks were then summated and displayed on the MNI152 template (see Fig. 1).

2.1.3. Reaching for tools and abstract objects

The apparatus consisted of a 41×38 cm box with a central shelf which was placed on a tabletop at midline and at a distance adjusted to be at full arm's length for each participant. Small magnets allowed a pair of stimulus objects to be positioned vertically on the top and bottom shelves, but able to be easily removed when grasped. Bright light emitting diodes (LEDs) were positioned below each stimulus object to act as a cue for which of the pair to reach for, and electronic sensors detected when an object was removed. The four stimulus objects were two everyday tools which required distinctly different methods of grasp for use (a comb and a toothbrush) and two abstract objects (a bar and a rod of similar overall dimensions to the comb and toothbrush respectively). In the *tools condition* the comb and toothbrush were positioned either upright or inverted (see Fig. 2a) on the top and bottom shelves. Participants were asked to grasp the cued tool rapidly as if about to use it. In the *barrier avoidance* condition one of the tools was replaced with the corresponding abstract object and a hinged flap was pulled forwards to touch its left or right side. When the flap was closed on