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IDEOMOTOR APRAXIA AND FUNCTIONAL ABILITY

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Abstract

The impact of ideomotor apraxia (IMA) on functional ability has been a relatively neglected topic in research. This has been due to the continued focus on performance on gesture imitation and pantomime of tool-use, together with widespread acceptance of anecdotal evidence that IMA has no effect when directly manipulating objects. An increasing number of studies have shown that IMA does in fact result in increased clumsiness when handling objects and may contribute to disability in everyday life. However the effect seems relatively mild compared to the stark abnormalities on gesture imitation and pantomime. The conventional explanation for this is that the cues provided by naturalistic contexts improve retrieval of action representations, but an alternative account concerns task-specific cognitive demands. Performance on simple prehensile tasks can be successfully guided by physical affordances whereas motor tasks may be failed if they require the support of memory or problem solving ability. A central deficit in IMA may be impaired postural representation causing inability to solve the problem of how to manipulate objects where neither affordance nor memory can dictate action. However, this account still fails to explain fully the patterns of error seen on complex naturalistic tasks such as dressing. Future research needs to further our understanding of how IMA maps on to disability, which will have implications for theory building and for therapeutic intervention.

Key words: apraxia, motor skill, affordance, rehabilitation

Introduction

Apraxia is commonly defined as a disorder of learned skilled movement (Rothi and Heilman, 1997; Buxbaum, 2001), but a peculiarity of research into ideomotor apraxia (IMA) is that there has been relatively little detailed investigation of dexterity. The reasons for this are largely historical. In Liepmann's pioneering studies at the start of the twentieth century he used pantomime of object use and imitation of gesture to elicit deficits and explore the relationship between concept and action (Goldenberg, 2003). It emerged that these methods were sensitive to a selective impairment after left hemisphere damage, and this impairment in imitation or pantomime is now accepted as the defining feature of IMA. Over the decades it has been repeatedly noted, often as an aside, that ideomotor apraxics do not seem to be significantly impaired when handling real objects or in naturalistic action. For example, De Renzi et al. (1980) commented that "in the great majority of cases [apraxia] only appears in the testing situation and does not trouble the patient in everyday life" (p. 9). This anecdotal evidence of normality in everyday settings has kept the focus of research on imitation and pantomime, where deficits are strongly displayed and any impact on dexterity or naturalistic action has not been investigated in depth. This is unsatisfactory for both theoretical and clinical reasons. In building a theory of IMA, there is a need to fully explore the manifestations of apraxia in all contexts, including naturalistic action and manipulation of real objects. From a rehabilitation perspective, the final concern is seldom about deficits in pantomime or imitation but on whether there are implications for dexterity and everyday actions. This paper will review the limited evidence on the impact of IMA on functional ability, consider theoretical and clinical implications, and outline some priorities for future work.

A continuing source of confusion in this field has been the absence of clear and consistent definitions. The general definition of apraxia as a disorder of skilled action not due to motor or sensory loss, is too broad to be useful since abnormalities in actions can arise for a multitude of reasons after brain damage. For example, the demented patient who is unable to use a knife and fork may be suffering from any of a range of attentional, perceptual, semantic or executive deficits. In this paper the focus will be on IMA, and we define this as an inability to pantomime object-use or to imitate gesture which is normally seen after focal left parietal or left frontal damage (Haaland et al., 2000). It must be recognised that even this simple operational definition is not free from difficulties as there are important differences between patients. For example, ability to imitate gesture can dissociate from inability to pantomime tool-use (Dumont et al., 1999). However, the working hypothesis which underpins most of the published work on IMA is that there is damage to a system for the control of skilled action and that differences in individual pattern of deficit reflect variations in which parts of this system have been impaired. This leads to the general prediction that a diagnosis of IMA should have implications for the wider control of action as seen in the functional tasks of everyday life. This aim of this paper is to review the evidence on these functional consequences.

Another problem of definition has been whether and how a distinction is made between IMA and ideational apraxia (IA). This distinction has its origins in Liepmann's insight (Goldenberg, 2003) that difficulties in performing actions might be due either to the loss of the concept of an action (IA) or an inability to execute the related motor programme (IMA). There is general agreement (De Renzi, 1985; Hanna-Pladdy et al., 2003) that such a distinction should be made on the basis that the ideational apraxic will show loss of action concepts by making inappropriate movements (content errors), whereas the ideomotor apraxic will show movements that are appropriate but spatially or temporally inaccurate (accuracy errors). Clear evidence for the existence of these two forms of apraxia comes from the study by De Renzi and Lucchelli (1988). These authors investigated a group of left hemisphere lesioned patients who were diagnosed as showing IA because they exhibited a high rate of content errors on multiple-stage tasks, such as lighting a candle with a match. A dissociation from IMA was indicated by the absence of a correlation between rate of these content errors and accuracy on a gesture imitation task, and the presence of individuals who were selectively impaired on either one of these tests. However, in practice, making this distinction is difficult because there is often no clear boundary between grossly inaccurate performance and a content error. For example, if when asked to pantomime slicing bread a patient makes a chopping rather than a slicing motion (Poizner et al., 1995), this could be due to inaccurate control of co-ordination of arm joints or loss of knowledge of how bread is sliced. In reality, it seems that both types of deficit may be present in many cases – De Renzi and Lucchelli (1988) found co-occurrence of IMA in 75% of their cases of IA. For the purposes of this paper, we will side-step this issue of the IMA/IA distinction by focussing initially on whether failure of any type on tests of imitation or pantomime has predictive validity for function. This will then lead to consideration of the nature of errors.

In the complex confusion of the research literature on apraxia it can be easy to lose sight of the fact that IMA is a common consequence of left hemisphere damage. De Renzi et al. (1980) tested a large sample of stroke patients with neurological signs of left hemisphere damage (100 cases) or right hemisphere damage (80 cases). Abnormality in imitation of gestures was detected in 20% of the right hemisphere cases and 50% of the left hemisphere cases. In a more selective sample of consecutive stroke ward admissions with brain scan evidence of parietal or posterior frontal damage, Sunderland et al. (1999) found impaired gesture imitation in 66% of left hemisphere cases while a marginal impairment was seen in 13% of right hemisphere cases. This solid evidence of a high incidence of IMA after left hemisphere damage gives impetus to theoretical and clinical research – we are not dealing with some rare or non-specific disorder but a common selective deficit whose nature and clinical implications need to be fully understood.

The first section of this paper reviews the evidence of the impact of IMA on functional ability. The aim here is to reveal what we know about the ecology of IMA as a phenomenon affecting functional ability. The second section of the paper (Explaining Preserved Ability) places this ecological evidence alongside evidence from experimental studies to consider how well we can explain the observed patterns of behaviour.

THE FUNCTIONAL IMPACT OF IMA

Studies of Dependence and Complaint

Studies to test the assertion that IMA "does not trouble the patient in everyday life" can be divided into those that have observed performance on functional motor tasks and those that have looked for correlations between functional dependence and apraxia scores. An example of the latter is the study of left hemisphere stroke patients 6 months after discharge from hospital by Sundet et al. (1988). They reported that gesture imitation scores were a significant predictor of questionnaire ratings of dependency on care-givers for help in activities of daily living (ADL), and concluded that IMA had a significant impact on functional outcome. The weakness of such correlational studies is that IMA is never seen as an isolated deficit. Multiple regression analysis was used by Sundet et al. (1988) to provide statistical control for some confounding variables such as the impact of hemiplegia on dependency scores, but there may be other important confounding variables. Consequently, this result cannot be taken as more than circumstantial evidence that IMA may increase dependence. In this context, it is interesting to note some negative findings. Both Walker and Lincoln (1991) and Hanna-Pladdy et al. (2003) found that IMA scores were not a predictor of dressing ability. The manipulation of clothing when dressing requires the execution of complex learned action sequences, and preservation of this skill would support the assertion that IMA does not translate into everyday life. However, as discussed below, there is evidence from direct observation that IMA can impact on dressing but interacts with other factors to obscure any direct correlation. The conclusion on correlational studies is therefore that they are inadequate to assess the functional impact of IMA – the presence of correlations could be due to confounding variables, whilst their absence could be due to interactions between the multitude of variables which can affect dependence.

There is a consensus that few patients with IMA complain about any impact on everyday life (De Renzi et al., 1980; Foundas et al., 1995), but the reasons for this may again be complex. In a study of patients with cortical damage six months after stroke (Sunderland, 2000), questionnaire ratings of dexterity problems such as difficulty in using eating implements were very high for some apraxic patients, but others reported fewer problems than those without apraxia. However, there was evidence that people found it difficult to find a meaningful point of comparison in deciding whether things should be labelled as problematic. Non-apraxic patients with hemiplegia or their carers were likely to say there was "no problem" with activities such as tying shoelaces which require bimanual control for normal performance. Presumably, they meant that the task could be successfully completed in one-handed fashion, which they saw as a significant achievement rather than a problem! Interestingly, the most frequent dexterity problems were reported by a patient with severe IMA but no hemiparesis, suggesting that in other cases the major deficits in motor skill due to right-sided hemiparesis may have overshadowed any impact of IMA on function with the ipsilesional hand. Furthermore, any clumsiness that is noted by the patient or carers is often ascribed to use of the non-dominant hand for most everyday tasks.

In summary, studies of dependency and complaint make the obvious point that for the typical stroke patient there are many deficiencies in functional skill which "trouble them in everyday life"; the difficulty is in finding solid evidence that IMA contributes to these troubles. To do this we probably have to turn to direct observation of motor performance rather than relying on dependency ratings or patients' complaints.

Use of Tools or Objects under Test Conditions

It is a common clinical observation that the apraxic patient who is unable to pantomime how a tool would be used seems to be able to demonstrate use when handed the actual tool. However, where this has been studied in detail, it appears that actual tool use is not entirely normal (De Renzi and Lucchelli, 1988; Poizner et al., 1995; McDonald et al., 1994; Goldenberg and Hagmann, 1998a). As with the previously discussed studies of dependency and complaint, a major issue is again how much this can be ascribed to IMA as opposed to other causes. The traditional view in apraxia research has been that testing ability to pantomime or imitate is a way of demonstrating disruption of some of the same neural systems that are involved when handling actual objects (De Renzi, 1985). From a modern perspective this is a bold assumption. It seems that action relies on parallel pathways and multiple dynamic spatial representations (Buxbaum, 2001) and it is not clear which of these systems may be recruited when no actual object is present (Westwood et al., 2000). It is therefore important to critically evaluate correlations between gesture or pantomime and actual object use to determine whether there is evidence of a shared underlying deficit. Direct observation of object use allows us to ask not only whether there is a correlation but also whether the pattern of errors suggests a common cause. The weight of evidence is in support of this and the most convincing studies are reviewed below.

De Renzi and Lucchelli (1988) selected 20 left hemisphere patients in whom clinical observation suggested a problem in handling objects appropriately. They were assessed on 5 tests of manipulation of multiple objects, such as opening a bottle with a bottle opener then pouring the drink into a glass. They were also tested on pantomime of tool use and ability to imitate gestures. A control group of patients with right hemisphere damage only made minor errors on the multiple object test whereas the majority of the left hemisphere group made both content errors (e.g., putting the bottle opener into the glass) and accuracy errors (i.e., appropriate but inaccurate movements). A gesture imitation test was also included and a significant proportion of the sample were impaired, suggesting IMA. There was however no correlation between severity of IMA and frequency of content errors. However, a re-analysis of the data presented by De Renzi and Lucchelli (1988) indicates that there is a significant correlation ($r = 0.31$) between severity of IMA and accuracy errors. So their data is entirely consistent with the view that IA and IMA occur as independently operating deficits – the former causing content errors, and the latter accuracy errors.

Evidence of the predictive value of gesture imitation for accuracy in object manipulation also emerged in the study by Sunderland et al. (1999) which included 15 patients with recent left parietal or posterior frontal damage. There was a significant impairment on simulations of everyday dexterity such as ability to spoon-up beans and deposit them into a container, or to unlatch and open a cupboard door. Accuracy errors were the most common, such as clumsiness when unlocking the latch, but in no case were these errors so severe as to prevent eventual success in completing the functional tasks. In a multiple regression analysis controlling for severity of stroke, a brief test of imitation and pantomime (Kimura and Archibald, 1974) emerged as a strong predictor of frequency of errors on the dexterity tasks, whereas other variables such as severity of aphasia or visuospatial ability did not.

Evidence of a shared pattern of errors in pantomime and in actual use of objects emerged from the study by McDonald et al. (1994), who investigated cases of dominant hemisphere damage, most of whom were aphasic. Demonstration of use of 12 objects was assessed by pantomime to command, imitation and when holding the actual object. Accuracy and content errors were assessed by two raters, with high inter-rater agreement. Normal controls made few errors but a majority of patients were impaired in at least one test condition and only 11% of patients did not make errors when handling actual objects. The pattern of errors was similar in all conditions, with accuracy errors being the most frequent. A more objective measure of error type was obtained in the study by Clark et al. (1994) who used motion analysis to investigate performance during pantomime and when using actual objects. In both conditions apraxics showed difficulty in producing movement in the correct plane and poor co-ordination between the joints of the arm (Poizner et al., 1995), leading these authors to propose a shared deficit of disruption of spatiotemporal representations of action.

In summary, there is solid evidence that impaired imitation or pantomime is associated with clumsiness when handling actual objects. Furthermore the quality of errors seems similar in pantomime and actual object manipulation. This is entirely in line with the classical theory of IMA, that impairment on gesture or pantomime is indicative of a more general disorder of skilled action, and we can put aside worries that correlations might not indicate a common cause under these very different task conditions. However, two questions arise. From a theoretical standpoint we can ask why the impairment with actual objects seems relatively mild, while from a rehabilitation perspective we can ask whether this mild deficit in a test situation translates into a disability when using objects in their normal functional context.

Activities of Daily Living

The basic ADL such as dressing, grooming and eating are complex tasks involving a diverse range of perceptual, cognitive and motor skills. The picture may be further complicated after stroke by the presence of hemiparesis, which prevents completion of these tasks in a normal bimanual fashion. It is therefore difficult to say if and how IMA impacts on performance. However, evidence that there is an impact comes from several studies. Function within a wholly naturalistic context was studied by Foundas et al. (1995), who videotaped 10 aphasic patients as they ate lunch. All succeeded in eating the meal but compared to neurologically normal controls, patients were more disorganised in sequencing their mealtime behaviour and clumsy in their use of eating implements. There was a significant correlation between the frequency of these action errors and errors on a gesture-to-command test (Florida Apraxia Battery). Furthermore, there was a trend towards a higher incidence of errors involving use of eating implements compared to errors in non-tool actions such as moving a bowl. Foundas et al. (1995) interpreted this as evidence of a selective effect of apraxia rather than general clumsiness due to hemiparesis.

Goldenberg and Hagmann (1998a) studied aphasic patients as they carried out 3 ADL tasks – buttering bread, donning and doffing a T-shirt, and cleaning teeth. Only 25% of the sample were able to complete the tasks without error, and 17% were unable to complete any task. The total frequency of errors (content and accuracy combined) correlated significantly with tests of imitation or pantomime but was only weakly related to severity of aphasia, suggesting a specific impact of IMA. T-shirt dressing was studied in detail by Walker et al. (2004) in a study of recovery of independent dressing in a representative sample of stroke patients. IMA was assessed using the Kimura Box (Kimura, 1977) which requires imitation of 3 hand postures in sequence to press a button, pull a handle and press a bar. It emerged that patients with IMA were able to dress independently if they had sufficient power in the right arm to use a normal bimanual strategy. However where there was hemiplegia requiring the deployment of a new unimanual strategy, no apraxic patient was able initially to put on a T-shirt.

Goldenberg and Hagmann (1998a) and Walker et al. (2004) came to similar conclusions regarding the impact of IMA on basic ADL tasks – when a motor task such as dressing can be completed using an over-learned strategy then the apraxic patient may be successful, whereas if hemiparesis demands discovery of a new compensatory strategy then IMA will present a barrier. This interaction between hemiparesis and apraxia may explain why IMA has not emerged as a simple correlate of dressing ability in other studies (Walker and Lincoln, 1991; Hanna-Pladdy et al., 2003).

It is not clear if specific effects of IMA can be observed in the case of more complex naturalistic tasks. Goldenberg et al. (2001) studied tasks such as changing the batteries in a tape recorder. It was found that apraxic patients exhibited more difficulties than left hemisphere patients without apraxia, who in turn were impaired compared to controls. Goldenberg et al. (2001) suggested that IMA may act as an additional factor, augmenting the difficulties caused by left hemisphere damage alone, but acknowledged the alternative possibility that the greater deficit in the apraxic cases might reflect a non-specific depletion of cognitive resources where brain damage is severe. They concluded that such complex naturalistic tasks may display "cognitive opacity". In other words, the complexity of the interaction between actor and environment may be such that we are unable to detect the impact of specific neuropsychological deficits. A similar conclusion was reached by Schwartz et al. (2002) who studied tasks such as making a packed lunch and found a similar pattern of errors in normal controls and in those with right or left hemisphere brain damage. While it is plausible that such complex naturalistic tasks may indeed be cognitively opaque, it is worthy of note that both Goldenberg et al. (2001) and Schwartz et al. (2002) used error rating schemes which focussed on content errors such as the inappropriate use of objects or omitting part of the required action sequence. Accuracy errors (clumsiness when handling objects appropriately) were not considered in detail. As the evidence from studies regarding the handling of objects discussed earlier is that IMA is associated with accuracy rather than content errors, then this might explain the failure to find evidence of specific effects of IMA on these complex tasks.

To summarise, the evidence is fairly clear that IMA does disrupt ADL tasks where there is a requirement to deploy non-routine motor strategies. This being so, it must have an impact on more complex naturalistic tasks as well, but it may be difficult to distinguish that impact of IMA from the multitude of other factors which will affect performance. However it may be that future studies which focus on accuracy rather than content errors will detect specific effects.

Explaining Preserved Ability

This review has shown that we can discard the traditional view that IMA has no functional impact, but it has to be acknowledged that the functional deficit is relatively mild. While patients with IMA show clumsiness on naturalistic tasks, apraxia seldom prevents eventual success in completing tasks (Foundas et al., 1995; Sunderland et al., 1999). The conventional account for why the effects are mild in most cases has been that contextual cues can support performance. For example, De Renzi et al. (1980) suggested that action representations that are inaccessible for controlling imitation or gesture to a command can become available if "elicited by a particularly strong flow of stimulation" (p. 10) as found within a natural functional context. So, the chain of events leading to waving goodbye in a natural context will prime the appropriate action even if there is a weakened representation of that action so that it cannot be accessed out of context on command or by imitation. The less obvious deficit seen when handling actual objects than when pantomiming object use (Clark et al., 1994; McDonald et al., 1994) might also be explained in these terms with the increased stimulation received from proprioceptive and visual inputs when handling actual objects serving to access damaged action representations. However, such contextual effects have not been investigated in depth and alternative explanations are possible. For example, the presence of physical objects may constrain movement so that even if the action representation is not more accessible, movements might fall into a more normal pattern. Also, naturalistic tasks tend to be forgiving of slight errors in performance. This was illustrated by the study of functional dexterity tasks by Sunderland et al. (1999) where, although apraxics showed multiple accuracy errors, these could be self-corrected and a successful outcome achieved. Close observation showed that an apraxic patient might make multiple inaccurate attempts to position their fingers around a card to turn it over but these occurred in rapid succession and the desired outcome was achieved fairly rapidly, albeit with greater effort than for normal controls.

It would be interesting to compare actions under conditions of subtle changes in context, such as following a command to stir water with a spoon *versus* stirring a cup of coffee prior to drinking it. Only when such research has been done could we decide if the improvements when performing actions in context is due to action representations being "elicited by a particularly strong flow of stimulation" or simply reflects the different nature of a task when physical props are provided.

The combined effects of contextual cueing and the forgiving nature of functional tasks may therefore explain much of preserved everyday ability. However, it also appears that some functional tasks are inherently less affected by IMA than others. Sunderland and Sluman (2000) compared performance across different dexterity tasks. This study included 15 patients with left parietal or frontoparietal damage, 11 of whom showed IMA on imitation or pantomime. An initial analysis (Sunderland et al., 1999) had shown that severity of IMA was a selective correlate of overall rate of dexterity errors but Figure 1 indicates that certain dexterity tasks were more affected than others. There were frequent accuracy errors on the bean spooning task described earlier and there was a milder deficit on turning over cards placed flat on the table top. In contrast, there was no significant accuracy deficit on picking up small objects such as a coin or a paperclip, or in stacking 4 wooden discs (checkers) to form a tower – all apraxic patients in the study were within the normal range on checker stacking. Other studies are consistent with this finding of no deficit related to IMA on some dexterity tasks. Haaland (1984) found no correlation between IMA and speed on a pegboard task, and Kimura (1993) reported that apraxics were as fast as non-apraxic left hemisphere patients in rapidly screwing a nut up and down a bolt.

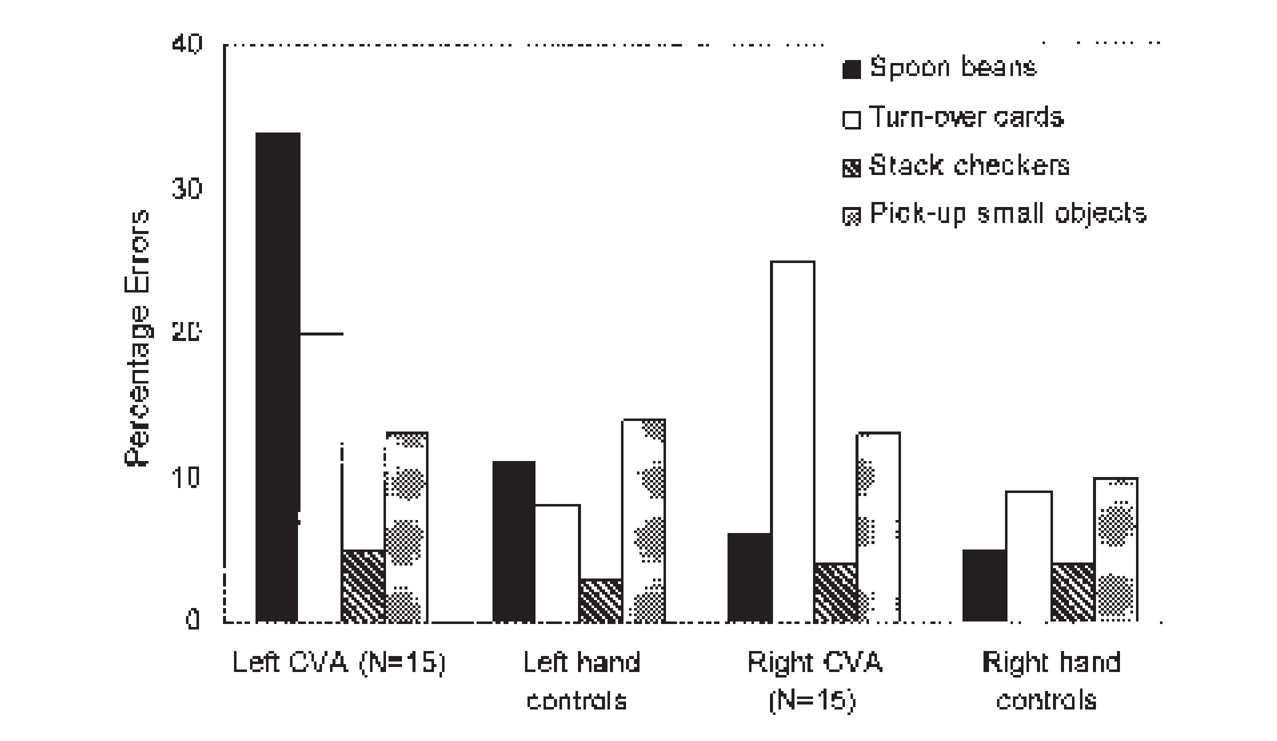

Fig. 1 – *The frequency of accuracy errors on different dexterity tasks for stroke patients with left or right hemisphere damage, and age-matched controls using the left or right hand (from Sunderland and Sluman, 2000).*

Apraxia and Physical Affordance

We suggest that a partial explanation for this pattern of abilities on dexterity tasks is that apraxics retain control of reaching and grasping under perceptual guidance. Hermsdorfer et al. (2003) studied patients with left hemisphere damage, two thirds of whom had mild or severe IMA, as they reached with their left hand for cylindrical objects placed vertically in front of them. They showed normal increases in velocity of reach with more distant cylinders, together with preserved ability to scale the aperture of their grasp to different diameters of cylinder. Compared to normal controls, there was some increase in total movement time and some abnormalities in kinematic profile of the reach-to-grasp response, but there was no correlation between these abnormalities and severity of IMA. The overall picture of the effect of left hemisphere damage on prehension is therefore that the basic skills of reaching and grasping with the left hand remain, albeit with some deficits in the control of timing of movement trajectory (Haaland et al., 2004), which are probably of separate origins from IMA (Hermsdorfer et al., 2003). Reduced accuracy related to IMA has been found for rapid aiming movements to the smallest visual targets (Haaland and Harrington, 1994) or reaching in conditions of restricted visual feedback (Haaland et al., 1999; Hermsdorfer et al., 2003) but not under less demanding conditions.

To what extent could this preservation of simple prehension explain the performance of different dexterity tests shown in Figure 1? An important characteristic of simple prehension is that the shape of the emerging grasp may be dictated by the structural properties of the target object (Jeannerod et al., 1995). This will be the case when the object offers few degrees of freedom in how it can be grasped or manipulated; that is to say, it offers a strong *physical affordance* (Norman, 1988). So the apraxic patient may have an intact route to action sufficient to perform functional tasks such as picking up a small object where a precision grip of a certain amplitude is afforded by the object. Other dexterity tasks present more degrees of freedom or require physical attributes to be secondary to other factors. The card turning task in Figure 1 offered many degrees of freedom in how the cards could be picked up and turned over (control subjects showed 7 different strategies), and the bean spooning task would also be influenced by knowledge and experience of using a spoon.

The Role of Memory for Action

Figure 2 suggests three major influences on ability to manipulate objects. This is not an information processing diagram, but a conceptual framework which specifies three different categories of explanatory factor which may be important in understanding apraxic behaviour. The first of these is physical affordance, and, as discussed above, this may underpin good performance of apraxic patients on some tasks. A second broad category is the use of memory to

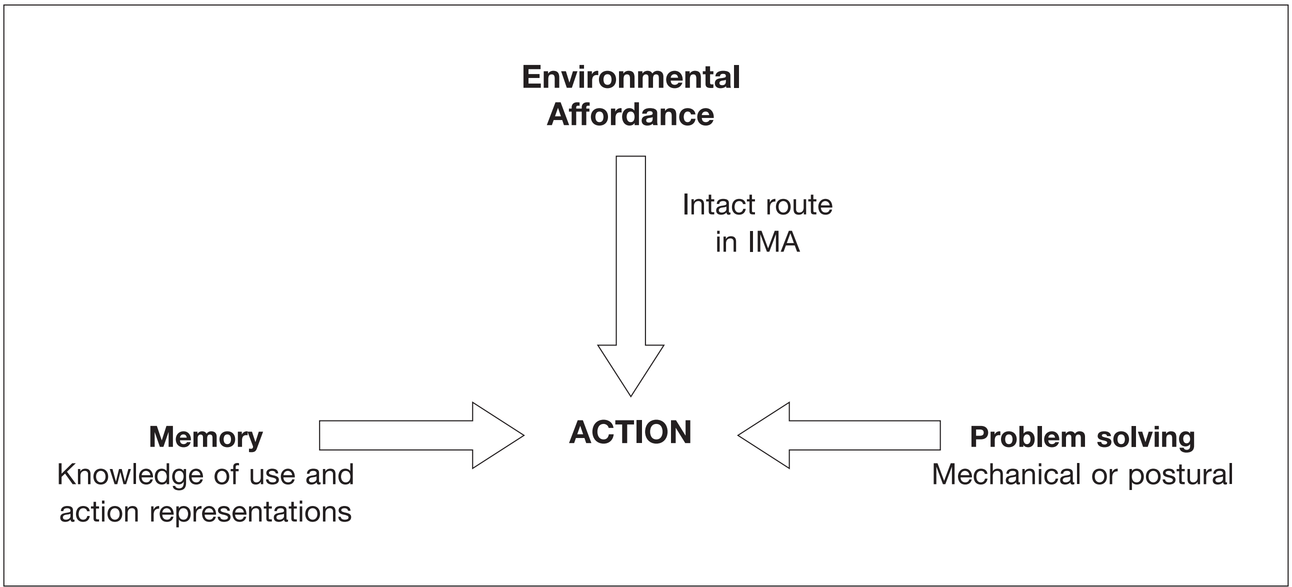

Fig. 2 – *Three major influences on ability to manipulate objects. Memory and problem solving may be disrupted in IMA but the intact affordance-led route allows manipulation of objects where the structural characteristics of objects and/or the biomechanical constraints of the context guide appropriate action.*

guide action, within which we include both memory for actions and semantic knowledge (e.g., knowledge of what specific tools are used for). We have seen that the pattern of errors in object manipulation supports the distinction between IA and IMA, with the former giving rise to content errors and the latter to errors of accuracy of execution. This implies that if disturbed memory for action is a key factor in explaining disturbed object manipulation in pure IMA, then the deficit is more procedural than semantic. This is in line with the conventional theory of IMA which is that it is not due to loss of knowledge about how objects are used but to disruption or disturbed read-out of mental representations of movements (visuokinesthetic engrams; Rothi and Heilman, 1997).

A corollary of this engram theory would seem to be that habitual actions should be more affected by IMA than novel ones, because habitual actions rely on memory whereas novel actions do not. The limited available evidence on functional ability points in the opposite direction. This was noted for complex tasks such as dressing (Goldenberg and Hagmann, 1998a; Walker et al., 2004) where difficulties emerged when patients had to learn novel dressing strategies to compensate for hemiparesis but not when previously learned routine procedures could be used. The vast majority of research related to action engram theory has stayed within the Liepmann tradition of investigation of imitation or pantomime, and implications for object manipulation and functional ability are therefore not entirely clear. Recent theorizing within this tradition has focussed on single case dissociations in ability to imitate familiar meaningful *versus* novel meaningless gestures, and contrasts between ability to produce or recognise gestures. This has lead to the suggestion that there are sub-types of IMA, with impaired memory for action being crucial in only one of these. Buxbaum (2001) termed this sub-type “representational IMA”, in which damage to action engrams is demonstrated by deficiency in gesture recognition (Heilman et al., 1982). Buxbaum (2001) contrasts this with “dynamic IMA” in which intact gesture recognition combined with impaired imitation of meaningless gestures indicates a problem with spatiomotor processing but not with action memory. The implications of this model for functional ability have yet to be explored. For example, might it be that the high rate of errors on the bean spooning task in Figure 1 is due to the inclusion of cases of representational IMA where memory for action is impaired whereas dynamic IMA accounts for errors on novel tasks such as card turning? Future research on functional ability will need to distinguish these sub-types.

Postural Problem Solving

There are many naturalistic tasks where action can neither be entirely affordance led nor dictated by memory. For example, when faced with opening a door with an unfamiliar latch, the structure of the door handle will afford grasping it in a particular way and memories of the actions required by familiar latches may help in attempting to open it. However, a degree of problem solving ability will be required to discover how this particular latch operates and what orientation of grasp is necessary to open it efficiently. The third process indicated in Figure 2 is therefore the use of problem solving to tackle novel tasks. If a problem solving deficit is central to IMA then this could explain why the apraxic deficit tends to emerge when hemiparesis forces the learning of new strategies for tackling functional motor tasks (Goldenberg and Hagmann, 1998a; Walker et al., 2004). However the evidence on the nature of any problem solving deficit in IMA is not yet clear. Goldenberg and Hagmann (1998b) studied the relationship between errors in use of actual tools and pantomime of tool use in a group of left hemisphere damaged aphasic patients. They interpreted deficits in pantomime as indicating impaired semantic memory of "instructions of use" for the tools but found that it was a poor predictor of errors in actual tool use. Only when patients were also impaired on a mechanical problem solving task was there a consistent deficit in actual tool use. Sunderland and Sluman (2000) suggested that the problem solving deficit which was specific to IMA related not to mechanical reasoning but to mental representation of body posture. That is to say, that when neither physical affordance nor memory dictated how an object should be handled then there was a requirement to mentally model what configurations of grasp could be used to manipulate it. So, the interpretation of the profile of performance shown in Figure 1 was that the large number of degrees of freedom in how objects could be grasped for card turning required that a mental simulation of grasping be used to determine the most efficient strategy. Similarly bean spooning, because it involved use of the non-dominant hand, could not be performed by relying on action memory but required postural problem solving.

Evidence consistent with there being a deficit in a high level representation of body posture in IMA can be drawn from several sources. A general finding is that ideomotor apraxics make spatial errors in imitation of gestures, leading Buxbaum (2001) to define her sub-type of dynamic IMA as due to deficient calculation of information about spatial relationships between body parts. More specifically, Goldenberg (1995) found that ideomotor apraxics were not only unable to imitate gesture but also were unable to model the gesture on a life-size mannikin, suggesting a conceptual deficit in appreciation of body configuration. Finally, consistent with a spatial deficit is the evidence that ideomotor apraxics show slightly reduced spatial accuracy when high demands are placed on awareness of limb position, for example when visual feedback is restricted (Hermsdorfer et al., 2003) or rapid aiming movements are made to very small visual targets (Haaland et al., 1999).

However, these latter studies also seem to raise a difficulty with the postural theory in that problems with egocentric spatial coding would seem to predict not minor but major inaccuracies in visuomotor control, including impairment on the simple prehensile tasks which we have seen are spared in IMA. In answer to this we would argue that the postural representation which is deficient in IMA is at a higher level than primary sensorimotor representation and is only called upon as a specialist left hemisphere system to solve problems where there is high demand on postural modelling. We can speculate that this is a function of the left inferior parietal lobe which is known to be involved in awareness of the body scheme (Haggard and Wolpert, 2005) and in the mental simulation of actions (Sirigu et al., 1996). Also, it must be remembered that all studies of object-related actions in IMA concern use of the ipsilesional left hand, which has unimpeded access to the motor control systems of the intact right hemisphere. It is interesting to note that affordance led action has been equated with the functioning of the dorsal route for action control (Norman, 2002) and that the right hemisphere dorsal route is intact in IMA.

The conceptual framework of Figure 2 therefore appears to offer a useful way of viewing the profile of functional disability in IMA, but further elaboration and expansion is needed. There is a need to explore the extent to which demands on problem solving abilities of the type outlined can successfully predict disability on a given task, and to compare this with accounts of IMA which place the focus of the deficit in disrupted action engrams for at least some patients (Buxbaum, 2001). An example of the challenge facing both accounts comes from the study of dressing difficulties in apraxia (Walker et al., 2004). The postural hypothesis might predict that IMA would lead to problems in learning to orient the garment and limbs appropriately, whereas an engram account might predict reduced accuracy of habitual action sub-components such as threading a limb through a sleeve. In fact, apraxics appeared to have no particular difficulty on either count when putting on a shirt but instead showed a persistent error of dressing the non-paretic arm first, leaving them entangled with the shirt when attempting to dress the paretic side. This perhaps suggests that theories of IMA which stress learning of motor sequences (Harrington and Haaland, 1992) might be more successful in predicting functional ability in this instance. Overall it is clear that we are still some way from having an understanding of IMA sufficient to predict its functional impact on different naturalistic tasks.

Conclusions

One firm conclusion is that anecdotal accounts of intact functional ability in IMA can be dismissed. There is solid evidence of an apraxic impairment when handling actual objects and circumstantial evidence of abnormalities in naturalistic action. The extent to which these translate into clinically significant disability remains unclear but it is plausible that IMA may be a major hidden obstacle in rehabilitation.

The conceptual framework we have offered suggests several directions for future clinical and theoretical work. Major theoretical concerns are to seek further evidence on the nature of the proposed postural impairment and also to extend the studies of the role of action engrams from traditional work on gesture imitation into work on object manipulation. Foremost among the clinical concerns are to clarify the relative benefits of supporting action through maximum use of physical affordance or through minimum reliance on postural problem solving, and to clarify if impaired memory for habitual actions is the critical deficit in a sub-group of apraxic patients with representational IMA.

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