Journal of the International Neuropsychological Society (2007), **13**, 993–996.
Copyright © 2007 INS. Published by Cambridge University Press. Printed in the USA.
DOI: 10.1017/S1355617707071573

SYMPOSIUM—INTRODUCTION

Complex object-related actions: Structure, meaning, and context

LAUREL J. BUXBAUM

Moss Rehabilitation Research Institute, Philadelphia, Pennsylvania

(Received August 29, 2007; Final Revision August 29, 2007; Accepted August 29, 2007)

All object-related actions are complex. Even the "simplest" of reach to grasp movements requires finely honed coordination of the muscles of the arm, hand, and fingers; is dependent upon exquisitely tuned feedforward and feedback mechanisms for motor control; is honed by learning; and is influenced by such cognitive factors as task goals. In this sense, then, the title of this Symposium, Complex Object-Related Actions, contains a redundancy. It is also true, however, that (as compared with, say, memory, language, executive function, attention, and spatial skills) the study of skilled action has been neglected within the fields of neuropsychology and cognitive neuroscience. One reason for this finding may be that many psychologists and neuroscientists do not view action as "cognitive" (Rosenbaum, 2005). As the work presented here illustrates, there is ample recent evidence suggesting that this view is inaccurate. We retain the word "Complex" in the title of the Symposium to emphasize the cognitive, psychological, and memory-related aspects of action that deserve broader interest. We suspect that the organizational principles and mechanisms that underlie cognition in many other domains will be found to play a role in the action system as well.

The study of complex object-related actions is in many ways a study of the workings of the two "visual" systems, and the interaction of these streams with systems mediating intentions and goals. However, much has changed since the two visual systems were originally elucidated in groundbreaking work by Ungerleider and Mishkin in the 1980s (Ungerleider & Mishkin, 1982). Based on work in the macaque, the ventral stream projecting from the occipital through the temporal lobes has been characterized as the system specialized for object knowledge (the "what" system), whereas the dorsal stream from the occipital through parietal and frontal cortices has been characterized as representing spatial and motor information for localizing and interacting with objects (the "where" or "how" system; Milner & Goodale 1995).

There are three major areas of development in this conceptualization that are reflected in the papers in this Symposium. The first is that there is an important division of labor within the Dorsal stream, such that actions based on object structure (e.g., shape or size) can be differentiated both neuroanatomically and behaviorally from actions based upon meaningful, skilled interactions with objects. The second area of development is a growing interest in the object-related action system as a memory system sharing mechanisms and properties with both declarative and procedural memory systems. This insight sets the stage for studies of learning and rehabilitation in patients with deficits in object-related action. The third development is the recognition that there is tremendous cross-talk between the dorsal and ventral streams and the executive system such that functional/semantic and motor information about objects is processed and selected differently depending upon task context, a finding with obvious implications for an ecologically valid understanding of object-related action. In the following sections, I briefly elaborate these three themes as they are reflected in the Symposium manuscripts.

FROM DORSAL AND VENTRAL TO "HOW TO" AND "WHAT FOR"

Several of the papers in this Symposium address the claim that there are two distinct ways of programming hand–object interactions: skillfully and meaningfully (e.g., as when using a familiar tool) or naively, based upon object structure (e.g., as when a poorly visualized object is speeding toward ones head). In most everyday cases, these two modes interact; however, they are also dissociable. For example, when picking up a computer keyboard to move it, one uses a prehensile hand posture that is independent of the keyboard's function, whereas functional keyboard use is

Correspondence and reprint requests to: Laurel J. Buxbaum, Moss Rehabilitation Research Institute, 1200 W. Tabor Road, Philadelphia, PA 19141. E-mail: lbuxbaum@einstein.edu

https://doi.org/10.1017/S1355617707071573 Published online by Cambridge University Press

associated with a nonprehensile "palming" or "poking" posture. Recent evidence from both monkey and human suggests that the Dorsal stream may be subdivided into two systems: a Dorsal–Dorsal system specialized for object prehension ("Grasp" system), and a Ventral–Dorsal system focusing on skilled, meaningful interactions with objects ("Use" system; Buxbaum, 2001; Frey, 2007; Rizzolatti and Matelli, 2003;).

Creem-Regehr et al. (2007, this issue) examine the topic of differences in the neural representations of novel objects when the objects are trained in one of two ways: as a functional tool, or as a shape to be manipulated and grasped without a particular function. The two sets of objects start out with the same visual and tactile characteristics, and only acquire their meaning (in the case of the "tools") or lack thereof (in the case of the "shapes") through experience. Indeed, these different training experiences prove to be associated with different patterns of neural activation in the Grasp and Use systems during functional magnetic resonance imaging scanning, whether the task during scanning was to use the objects or merely to examine and remember them. This suggests that representations of manipulable objects contain information about the distinct types of actions that have been associated with them, and has implications for theories of semantic object memory (c.f., Allport, 1985; Buxbaum & Saffran, 2002; Caramazza & Shelton, 1998; Martin & Chao, 2001).

Consistent with the work or Creem-Regehr et al. (2007, this issue), patients with object-related action disorders show dissociations in impairment in skilled functional actions versus prehensile actions. Patients with ideomotor apraxia (IMA) are frequently impaired in positioning the hand for use, but yet grasp normally for the purpose of picking up. Conversely, patients with a disorder of skilled reaching called optic ataxia have severe problems in grasping objects, while performing normally in positioning their hands for skilled object use.

Barde et al. (2007, this issue) assess whether the relative preservation of the Grasp system in patients with IMA can be exploited to the patients' benefit. They trained stroke patients with and without IMA to learn action–object linkages over several trials. The linkages of objects with strongly compatible actions (i.e., strong "affordances" for action) was better in the IMA patients (but not in the non-IMA patients) than the linkages of objects with weakly compatible actions. This, along with complementary findings from a detailed lesion analysis, suggests that damage to the Use system is associated with a stronger-than-normal reliance on structural action–object linkages mediated by the Grasp system.

LEARNING OF ACTIONS ASSOCIATED WITH OBJECTS: SKILLED ACTION AS MEMORY

Both the papers of Creem-Regehr et al. (2007, this issue) and Barde et al. (2007, this issue) use learning paradigms to train associations of novel actions with novel objects. The merit of this approach is that it offers control over object and action variables of interest. Desmarais et al. (2007, this issue) make full use of this opportunity to carefully explore the mappings between objects and actions that vary in their similarity. Essentially, they create a representational network by training subjects to produce several actions on several objects, and then derive a "confusability matrix" based on the patterns of errors observed when they required subjects to produce and identify the actions. They find that actions are confused more often when they have been associated with visually confusable objects. Thus, the actions' linkages to specific objects affect the action representations.

One intriguing question that has received relatively little attention is whether a network so trained is akin to a semantic network, a procedural memory system, or both. For instance, is the confusability of the trained action representations a function of their proximity in an abstract conceptual space, as has been postulated for semantic memories? Or, on the other hand, is confusability a function of the similarity of the actual movements performed, as has been found in other studies of object-related action (Bub et al., 2007)? The answer to these questions may prove informative to the development of training and rehabilitation strategies for patients with disorders of object-related action.

SELECTION OF OBJECTS FOR ACTION: WHAT AND HOW DEPEND ON WHY

It has long been recognized that the amount of available visual input is too vast for simultaneous processing, and that filtering and/or selection mechanisms must act to limit the information to that which is manageable. Early inquiries in this area focused on characteristics of stimuli making them more or less likely to be selected by attention (e.g., array density, stimulus similarity). In the past 20 years, there has been a burgeoning interest in the role of task context and the actor's goals and intentions in determining patterns of attentional allocation (Duncan, 1993).

Ecological approaches to the study of selection of objects for action hold that ease of selection is determined by the degree to which the information inherent in an object array is appropriate to the needs of the physical programming of a coordinated action (Michaels & Stins, 1997). Objects directly afford several possible actions as a joint function of object characteristics (e.g., shape, size, weight, texture, and location) and organism attributes (e.g., size and type of effectors, type of movements, motivation; Gibson, 1977).

What Is Attended and Perceived Depends on the Action to Be Performed

Several investigators (e.g., Castiello, 1996; Tucker & Ellis, 1998) have suggested that objects in the array automatically activate responses associated with them, even in the absence of the subject's intention to act. This phenomenon has been termed a "visuomotor priming" effect (Craighero

https://doi.org/10.1017/S1355617707071573 Published online by Cambridge University Press

et al., 2002). On the other hand, there are several lines of evidence that object affordances are indeed attended (and hence, activate their associated responses) differently depending upon the intentions and plans of the actor (Pavese & Buxbaum, 2002).

The paper of Bickerton et al. (2007, this issue) fits squarely within these recent traditions in the literature on selection for action, yet extends this line of work to the question of whether object prototypicality plays a role in selection. Patients with limitations in attentional resources due to subcortical and frontal lobe damage performed everyday action tasks such as making a cup of tea. Objects were either familiar, usual exemplars or unusual variants. Patients were more likely to fail to select and use the unusual as compared with the familiar objects, even when they had been recognized in pretesting. Bickerton et al. (2007, this issue) suggest that nonprototypical objects are associated with reduced bottom-up levels of activation and are thus subject to omission when limited attentional resources are diverted, in this case, to the overarching task. This is an example of the role of task goals and context in selection for action that is particularly relevant to activities of daily living.

FUTURE DIRECTIONS IN THE STUDY OF COMPLEX OBJECT-RELATED ACTION

The work of Bickerton et al. (2007, this issue) touches on the interesting question of whether the competitiveness of familiar objects in real-life tasks is solely a function of visual object familiarity, *per se*, or is also influenced by the strength of the actions linked to these objects. In previous investigations using arrays with a single target and single distractor object, Humphreys and colleagues (Humphreys & Riddoch, 2001) and Pavese & Buxbaum (2002), among others, have shown that objects strongly affording an action (e.g., a right-facing cup handle for participants using the right hand) are potent magnets for attention. Thus, when these highly graspable objects are presented as distractor (nontarget) objects, they significantly slow response times to target objects. But is this summoning of attention due to affordances for action additive with visual (nonmotor) familiarity? Might similarly potent distractor effects also be observed with objects that do not have strong *a priori* affordances, but that are trained to be associated with novel "Use" actions? The potential implications of such investigations for performance of real-life activities with meaningful objects is clear.

There are several other action domains in which "top-down" information about task context influences characteristics of the actions performed. For instance, in healthy subjects, the kinematics of object grasping change as a function of whether the task is to pick up or use an object (Friedman & Flash, 2007). As deficits in grasping and object use may dissociate, the study of grasp kinematics may yield insights into subtle aspects of action planning that are disordered in patients with skilled action deficits.

Finally, the study of the skilled object use system as a memory system is in its infancy. Unlike the domain of semantic memory, for example, almost nothing is known about the time course of activation of representations for using objects, and how such representations may interfere with (or prime) each other. Is "action space" organized like lexical/semantic space, with a proximity structure based on conceptual (or even motor) organization? What is the influence of action frequency, familiarity, or age of acquisition of actions on patterns of deficits seen in action-disordered patients? These issues have all proven important in the study of language deficits and language rehabilitation and may have important implications for theory development and rehabilitation of action disorders as well. For example, in the domain of alexia, it has been demonstrated, counterintuitively, that it is more effective (as well as explicable from a computational perspective) to re-train reading on semantically atypical words than words that are more typical of their semantic category (Plaut, 1996). As we pursue a better understanding of the fundamental organization of action representations, we can begin to see whether similarly useful insights may be gleaned in the domain of complex object-related action.

REFERENCES

Allport, D.A. (1985). Distributed memory, modular subsystems and dysphagia. In S.K. Newman & R. Epstein (Eds.), *Current perspectives in dysphagia* (pp. 32–60). Edinburgh: Churchill Livingstone.

Barde, L.H.F., Buxbaum, L.J., & Moll, A.D. (2007, this issue). Abnormal reliance on object structure in apraxics' learning of novel object-related actions. *Journal of the International Neurological Society*, *13*, 997–1008.

Bickerton, W.-L., Humphreys, G.W., & Riddoch, M.J. (2007, this issue). The case of the unfamiliar implement: Schema-based over-riding of semantic knowledge from objects in everyday action. *Journal of the International Neurological Society*, *13*, 1035–1046.

Bub, D.N., Masson, M.E., & Cree, G.S. (2007). Evocation of functional and volumetric gestural knowledge by objects and words. *Cognition*, [Epub ahead of print].

Buxbaum, L.J. (2001). Ideomotor apraxia: A call to action. *Neurocase*, *7*, 445–458.

Buxbaum, L.J. & Saffran, E.M. (2002). Knowledge of object manipulation and object function: Dissociations in apraxic and nonapraxic subjects. *Brain and Language*, *82*, 179–199.

Caramazza, A. & Shelton, J.F. (1998). Domain-specific knowledge systems in the brain: The animate-inanimate distinction. *Journal of Cognitive Neuroscience*, *6*, 83–97.

Castiello, U. (1996). Grasping a fruit: Selection for action. *Journal of Experimental Psychology. Human Perception and Performance*, *22*, 582–603.

Craighero, L., Bello, A., Fadiga, L., & Rizzolatti, G. (2002). Hand action preparation influences responses to hand pictures. *Neuropsychologia*, *40*, 492–502.

Creem-Regehr, S.H., Dilda, V., Vicchrilli, A.E., Federer, F., & Lee, J.N. (2007, this issue). The influence of complex action knowledge on representations of novel graspable objects:

https://doi.org/10.1017/S1355617707071573 Published online by Cambridge University Press

Evidence from fMRI. *Journal of the International Neurological Society*, *13*, 1009–1020.

Desmarais, G., Pensa, M.C., Dixon, M.J., & Roy, E.A. (2007, this issue). The importance of object similarity in the production and identification of actions associated with objects. *Journal of the International Neurological Society*, *13*, 1021–1034.

Duncan, J. (1993). Selection of input and goal in the control of behaviour. In A. Baddeley & L. Weiskrantz (Eds.), *Attention: Selection, awareness and control* (pp. 53–71). Oxford: Clarendon Press.

Frey, S.H. (2007). What puts the how in where? Tool use and the divided visual streams hypothesis. *Cortex*, *43*, 368–375.

Friedman, J. & Flash, T. (2007). Task-dependent selection of grasp kinematics and stiffness in human object manipulation. *Cortex*, *43*, 444–460.

Gibson, J.J. (1977). The theory of affordances. In R. Shaw & J. Bransford (Eds.), *Perceiving, acting, and knowing: Toward an ecological psychology*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Humphreys, G.W. & Riddoch, M.J. (2001). Detection by action: Neuropsychologcal evidence for action-defined templates in search. *Nature*, *4*, 84–88.

Martin, A. & Chao, L.L. (2001). Semantic memory and the brain: Structure and processes. *Current Opinion in Neurobiology*, *11*, 194–201.

Michaels, C.F. & Stins, J.F. (1997). *An ecological approach to stimulus-response compatibility*. Amsterdam: Elsevier.

Milner, A.D. & Goodale, M.A. (1995). *The visual brain in action*. Oxford: Oxford University Press.

Pavese, A. & Buxbaum, L. (2002). Action matters: The role of action plans and object affordances in selection for action. *Visual Cognition*, *9*, 559–590.

Plaut, D. (1996). Relearning after damage in connectionist networks: Toward a theory of rehabilitation. *Brain and Language*, *52*, 25–82.

Rizzolatti, G. & Matelli, M. (2003). Two different streams form the dorsal visual system: Anatomy and functions. *Experimental Brain Research*, *153*, 146–157.

Rosenbaum, D.A. (2005). The Cinderella of psychology: The neglect of motor control in the science of mental life and behavior. *American Psychology*, *60*, 308–317.

Tucker, M. & Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology. Human Perception and Performance*, *24*, 830–846.

Ungerleider, L.G. & Mishkin, M. (1982). Two cortical visual systems. In D.J. Ingle, M.A. Goodale, & R.J.W. Manfield (Eds.), *Analysis of visual behavior*. Cambridge, MA: MIT Press.

https://doi.org/10.1017/S1355617707071573 Published online by Cambridge University Press