The Role of Functions and Motor Actions in Early Tool Concepts

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Abstract

Recent imaging studies have found activation in areas associated with motion processing and motor planning during a range of cognitive tasks involving tools. This has led some researchers to conclude that motor information is central to the conceptual representation of tools. To explore this hypothesis, we used a two-alternative forced-choice task to examine whether children and adults use motor information to determine the extension of new tool categories. Adults, 5-year-olds and 3-year-olds were introduced to a novel tool ("a dax") and shown its function and how to manipulate it. Then two unlabelled tools were presented, one with the same function and one with the same motor manipulation. All three groups systematically extended the novel label to the tool with the same function rather than the one with same motor manipulation. Both 3- and 5-year-old children continued to extend by function when the function was imaginary and not perceptually accessible. We conclude that function is central to conceptual content of tool terms while motor information is not.

Introduction

What is a hammer? For over 30 years developmental and cognitive psychologists have debated whether artifacts are defined by their visual appearance, purpose, or origins. Recent work in cognitive neuroscience suggests a different answer —hammers and other tools could be defined by the characteristic movements used to employ them.

This hypothesis gains support from several lines of research implicating the same brain regions in the representation of motor movements and the conceptualization of tools. First, imaging studies have identified a network of regions that are active during the identification and naming of tools (relative to animals, faces or buildings). This network includes the left medial fusiform gyrus (left-MFG), the posterior middle temporal gyrus (PMTG), left intraparietal sulcus (left-IPS), and left ventral premotor cortex (left-VPMC) (see Martin, 2007 for review). This network is also active in nonpictoral tasks involving tool concepts, such as single-word reading, lexical decision, and word generation, suggesting that these regions are involved in representing the meaning of tool terms (Chao, Haxby & Martin, 1999; Kiefer, 2005; Vitali, Abutalebi, Tettamanti, Rowe, Scifo, Fazio et al., 2005). These regions are also implicated in processing movement. Left-MFG and PMTG are active in tasks involving artifact motion, while left-IPS and left-VPMC are active in tasks that involve motor representations such as planning, executing or imagining actions or tool usage (Boronat, Buxbaum, Coslett, Tang, Saffran, Kimberg & Detre, 2005; Decety, 1996; Johnson-Frey, 2004; Mahon, Milleville, Negri, Rumiati, Caramazza & Martin, 2007; Martin, 2007). During tool tasks activation in left-IPS and left-VPMC is affected by a participant's motoric experience with a particular tool type

(Weisberg, von Turennout & Martin, 2007), suggesting that these activations may reflect the retrieval of motor programs associated with tool use.

Findings such as these have generated a broad range of hypotheses about the role of motor information in conceptual processing (Barsalou, Simmons, Barbey & Wilson, 2003; Johnson-Frey, 2004; Mahon & Caramazza, 2008). Here we focus on one question raised by these data: to what extent is the conceptual content of tool terms motoric? There are at least three possible answers.

According to the *strong embodied cognition* view, motor cortex is activated during conceptual tasks because motor programs are central to the conceptual representation of some classes of words such as tool terms or verbs (e.g., Gallese & Lakoff, 2005; Glenberg & Kaschak, 2005; Rizzolatti & Craighero, 2004). In its clearest and most precise form, this amount to the hypothesis that the meaning of these terms consist of simulations of the actions associated with them. In the case of action verbs this view is made explicit by Glenberg and Kaschak who argue that "understanding an [action] sentence calls upon the same cognitive mechanisms as those used in planning and taking action" (p.561) and that "all of the components of knowledge [about actions] are action-based… The meaning of a situation to an individual is the set of actions available to that individual in that situation." (Glenberg & Kaschak, 2005, p. 15-16). Similarly, Gallese and Lakoff (2005) argue that understanding an action requires a mental simulation of the motor representations that are used in action and perception (p. 457). In other words, each verb is associated with a distinct pattern of movements, and this pattern is activated every time the concept is instantiated in thought. This hypothesis could be readily extended to the domain of tools. Many researchers define tools as manipulable

objects that have "direct relationships between their physical structure and the motor movements associated with their use" (e.g., Mahon et al., 2007). Thus, on the strong embodied hypothesis, we might argue that the meaning of a tool term is constituted by a simulation of the motor movements involved in using that tool. On this proposal recognizing a hammer or understanding the word *hammer* would require simulating the motor programs associated with the act of hammering, resulting in premotor and parietal activation.

Another view (a.k.a. the *weak embodied* view) is that motor programs only partially determine conceptual content – knowledge of an object is distributed among several relevant representational systems: sensory systems representing visual form, motor systems representing information about manipulation and perhaps abstract conceptual systems representing properties such as function or kind. For example, Martin (2007) suggests that "object concepts… emerge from weighted activity within property-based brain regions". This hypothesis raises the possibility that the relative contribution of different systems could change with experience. For example, early concepts may begin as primarily motoric with more abstract properties growing in importance during development. Alternately, the role of motor information in conceptual representations might depend upon expertise in tool use, becoming increasing important as children gain experience with the movements associated with particular tools..

A third possibility is that motor information does not constitute conceptual content either partially or wholly (a.k.a. the *abstract cognition* view). Instead, tool concepts have abstract meanings based on their current function (e.g., Kemler Nelson, Russell & Duke, 2000a; Kemler Nelson, Frankenfield, Morris & Blaire, 2000b) or their

creator's intentions (e.g., Diesendruck, Markson & Bloom, 2003).While this position has gained some acceptance in developmental psychology, the challenge for this position is to explain how and why brain regions involved in motion processing and motor representations become active in conceptual tasks. We will return to this issue in the discussion.

What is conceptual content?

These three theories differ in the role that motor information plays in determining the conceptual content of tool terms. Thus to distinguish between them we need a method of assessing what information determines the meaning of a concept. Patterns of neural activation alone cannot resolve this issue. Knowing that regions implicated in motor and motion processing are active in a conceptual task does, by itself, tell us the role that these regions play in conceptual processing. Do these regions represent the meaning of the concept or are these activations a downstream effect of retrieving that meaning?

One approach to understanding the content of concepts is to examine how they are extended. Theories of concepts vary in their explanatory scope and their construal of conceptual content. But theories which posit that concepts have content (contra Fodor, 1998) typically claim that this content is used to determine the extension of a concept, and thus guides categorization (Laurence & Margolis, 1999). For example, on the classical or definitional theory of concepts, the content of a concept consists of a set of features and these features are necessary and sufficient for category membership. In contrast, in the theory-theory of concepts, the content of a concept depends on its relation to other concepts. But again these relations determine what can be considered a category member and what cannot.

Because word meanings are generally assumed to be concepts, there is a long tradition (in both philosophy and psychology) of studying conceptual content by examining how people extend words to new exemplars. By systematically varying these exemplars we can test alternate hypotheses about the content of a concept. For example, I might believe that a *kitten* is a small cat, and you might believe that it is a young, immature cat. By presenting people with cats of different ages and sizes and asking which are *kittens*, we could easily determine who is right and thus come closer to understanding the conceptual content of the term. A task of this kind is well-suited to the question we raised above. If the conceptual content of tool terms consists of representations of the actions typically used to employ them, then these actions should guide word extension. Hammers should be those things which are swung with a characteristic extension of the forearm. If this is not the criterion for extending tool terms, then we will need to look for other explanations for the patterns of activation observed in tool tasks.

It is critical to note that the conceptual content does not exhaust conceptual knowledge. We clearly know more about categories than the criteria that determine their extension. Thus in the example above, if we confirm that people systematically reserve the word "kitten" for immature cats regardless of physical stature, we would conclude that immaturity, but not size, is part of the conceptual content of the term. But we would still have to account for the fact that people know that kittens are typically small and are likely to use that information when trying to spot kittens in the world. Thus the notion of conceptual content is distinct, at least in principle, from the notion of semantic memory or conceptual knowledge. Nevertheless conceptual content plays privileged role in

theories of concepts (Laurence & Margolis, 1999). Content individuates concepts: two concepts are different concepts if and only if they have distinct content (otherwise they are two tokens of the same concept). In containment theories (like most semantic feature theories) the content of a concept is invoked by each use of that concept. Even in theories which eschew the notion that concepts contain other concepts, such as theory-theory, the properties which determine categorization and individuate concepts also have a privileged role in guiding inference.[1]

Why study the development of tool terms?

In these studies we compare the extension of tool terms in adults and young children. There are three reasons for taking a developmental approach. First, in comparison to college students, preschoolers are less educated, less metacognitively savvy, less strategic and less metalinguistically advanced (for reviews see Flavell, Miller & Miller, 2002; Gombert, 1992). Perhaps, even as adults, our work-a-day concepts are rather simple in nature, but our exposure to scientific theories has made us aware of their inadequacies, leading us to supplement them with concepts that have more theoretically rich content (Fodor, 1998). This richer conceptual content might shape adult performance in a deliberate extension task, but its unlikely to be available to the young child.

Second, most developmental theories posit a shift from concrete sensory or motor concepts in infancy to more abstract concepts in adulthood (see Mandler, 2004 for discussion). In Piagetian theory this shift involves a conceptual change which allows the

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[1] In theory-theories the critical properties are typically called *conceptual structure* rather than *conceptual content* both to avoid the metaphor of containment and because the properties that individuate concepts are their relations to other concepts and thus they derive from the structures in which concepts are embedded. We will continue to use the phrase *conceptual content* for simplicity's sake with no intention of restricting ourselves to containment theories rather than inferential ones (see Laurence & Margolis, 1999).

child to supplement sensory motor schemas with abstract and increasingly complex

symbols. In contrast, theories of embodied cognition argue that concepts remain concrete

into adulthood. Nevertheless, such proposals often involve a developmental shift toward

abstraction. Some theorists suggest that concepts which are fundamentally sensory motor

nature may gain more abstract symbolic properties through their association with external

linguistic symbols (Smith & Gasser, 2005). Others argue that sensory or motoric detail

can be bleached out as concepts are metaphorically extended. For example, Glenberg

and colleagues make this argument in reference to verbs of transfer (Glenberg, Sato,

Cattaneo, Riggio, Palumbo & Buccino, 2008, pp. 907-8):

In this context [the one in which *give* is said to an infant] the meaning of transfer is
encoded as an action having as parameters a type of grasp (e.g., power grip), force related
to the object being transferred, and a direction of movement specified by the location of
the object (e.g., the self) and location of the recipient (e.g., the mother). Repetition of
actions of this sort leads to development of an action schema in anterior portions of
premotor cortex…which becomes the meaning of the verb "to give". . . . The basic action
schema can be associated with other verbs of transfer by generalizing the grasp and force
(i.e., the means of transfer) parameters. Thus, "Marco hands/throws/sends the papers"
can all be understood using the same schema with a change in the specification of the
means of transfer. The action schema is generalized for abstract transfer by using
communication as the means of transfer.

Thus the content of early transfer verbs like *give* is argued to be motoric, some process of

abstraction occurs which allow the child to pull out a notion of transfer from these

motoric representations, and this more abstract notion of transfer then becomes part of the

meaning of late acquired verbs of transfer such as *delegate* or *lease* which have no

motoric content of their own.   A parallel account might be envisioned for tools:

children's initial concept of hammer might consist (entirely or in part) of the motor

movements used to employ that tool, but by some process of generalization across many

uses of many tools, she might abstract away from the specific motoric properties of this

action to derive a more general notion of the tool's function.[2] By examining tool

extension in three-year-olds, five-year-olds and adults we might catch of glimpse of

abstraction in process.

Third, recent results from cognitive neuroscience suggest a very different

prediction about the developmental trajectory of tool concepts: Motoric representations

may actually become more important with age. Activation of motor regions during tool

identification is affected by participants prior experience with tools (Kan, Kable, Van

Scoyoc, Chatterjee & Thompson-Schill, 2006; Weisberg et al., 2007). For example,

Weisberg and colleagues introduced participants to novel tools and tested them in a

visual matching task. Initially activation in left-VPMC and left-IPS was no greater for the

tools than for scrambled images. But after participants were given experience using some

of the tools, activations emerged in both areas which were greater for those tools that the

participants had manipulated. As we noted earlier. these same areas have been found to

be active during tasks which involve the conceptual processing of tool terms (Chao et al.,

1999; Kiefer, 2005; Vitali et al., 2005). If we believe that these activations reflect the

conceptual content of tool terms, then Weisberg's results would suggest that tool

concepts only come to have motoric content through tool use. While tool use is

ubiquitous in humans, young children clearly have less experience with tools than adults.

Preschoolers are often forbidden from touching many of the tools they encounter (knives,

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[2] The alert reader might be dissatisfied with this story. It is unclear, in both cases, where the more abstract representations is coming from. If the child's initial representation is truly and solely motoric and she generalizes it by removing specific motoric content, then she should be left with nothing or with a very vague motoric representation. It is certainly not clear how the concept of "transfer" or concepts of specific functions could arise from this process. One gets the sense in the passage above that the notion of transfer is lurking there from the beginning in all its abstract glory. How can the "recipient" or the "object being transferred" be identified without such a concept? Thus the authors may be supposing that motoric representations include these abstract parameters as well. If not , Fodor's arguments against creation of new conceptual primitives would apply (1981; 1998)..

saws, mommy's laptop). They are also isolated from most activities of production and

thus are presumably exposed to fewer tool types than adults. Children's ability to

manipulate tools develops gradually. In many cases, the motor movements that

preschoolers employ are different from those used by adults (Rosenbloom & Horton,

1971) and more variable (Braswell, Rosengren & Pierroutsakos, 2007). For example,

although spoons are one of the earliest tools that children master, toddlers typically grasp

them using a variety of hand positions, none of which allow them to tilt the spoon

independent of their hand as adults do (Connolly and Dalgleish, 1989). These findings

raise the possibility that young children's motoric tool knowledge may not be stable

enough or complete enough to provide the conceptual content for tool terms.

The word extension task as a measure of conceptual content

To explore tool concepts across development, we need a task that taps conceptual

content and can be performed by young children. The present study employs the word-

extension task, a paradigm which assess the conceptual content that children assign to

novel words (Gentner, 1978; Markman & Hutchinson, 1984; Landau, Smith & Jones,

1988; Soja, Carey & Spelke, 1991).

When we examine the extension of previously acquired words it can be difficult

to determine which features are guiding extension and hence what the content of the

concept is. Real words typically label categories which overlap on multiple dimensions.

For example, hammers have similar functions and similar shapes, were created by similar

processes, and are used with a similar motor movement. Furthermore, since individuals

have had extensive experience with real tool categories, it is impossible to know how

they arrived at this particular content (was it their initial hypothesis about this concept or

were they forced to it by experience?). The word extension task allows us to avoid these complications by introducing participants to a novel word (and concept) and examining how they extend it. In such studies children are shown a novel object (the standard) that is labeled with a novel word (*dax*). Then they are shown two or more novel objects which are not labeled (the test objects). Typically each test object shares one feature with the standard. The child is then asked (directly or indirectly) which one of the objects is "another *dax*".

This task is accessible even to toddlers. Children as young as two will systematically extend a novel word to objects with the same shape, as opposed to objects with the same texture or color (e.g., Landau et al., 1988).. In contrast, when children are asked which object is most similar to the standard, their judgments are less systematic and sensitive to a variety of object properties. This suggests that word extension reflects children's knowledge about the concepts encoded by object labels rather than the raw perceptual similarity of the objects being categorized.

In fact, results from other paradigms suggest that even infants 9-14 months have systematic expectations about the extension of novel words (Waxman & Markow, 1995; Dewar & Xu, 2007; Dewar & Xu, 2009). For example, by 9 months of age infants who hear two different labels (Look a dax! Look a toma!) are able to infer that two objects with distinct shapes are present (Dewar & Xu, 2007). They look away more quickly when two objects with different shapes are revealed, but examine the display longer when two identical objects are revealed, or two objects with the same shape but different colors.   This bias to extend words by shape might reflect a deeper preference to interpret words as labels for more abstract kinds. By 10 months of age, infants expect that objects

which have different labels will have different internal properties even though their

shapes were similar (Dewar & Xu, 2009).

Previous word extension studies have focused on children's use of perceptual and

abstract features in the categorization of artifacts and animals. No studies have explored

the role of motor information in children's tool concepts. The research to date

demonstrates that toddlers can extend artifact labels by shape and by function. The

relation between shape and function is more controversial. Some studies find that shape

initially dominates, with extension by function increasing across development (Gentner,

1978; Smith, Jones & Landau, 1996). However, when researchers use functions which

motivate the external properties of the object, children as young as two privilege function

over shape (Kemler Nelson et al., 2000a). This has lead some theorists to posit that

children use shape primarily as a clue to what an object's current or intended function

might be (Diesendruck et al., 2003; Kemler Nelson et al., 2000ab).

Motion and Function in Children's Tool Knowledge

Two recent studies provide tentative evidence that motor information may play a

critical role in young children's conceptualization of tools. The first explored tool-

directed actions in one-year-olds (Barrett, Davis & Needham, 2007). Children were

given experience using a novel tool to perform a particular task (inserting it into a tube to

pull out pom-poms). One group was taught to hold the tool by its long skinny handle, a

second learned to hold it by a wide loop at the end, and third practiced holding it both

ways. Children were then given two new tasks. One task had a similar function (the tool

was inserted into a hole to turn on the light) but could only be performed by holding the

tool by the loop. The other task had a different function (using the loop to grab a handle)

and could only be performed by holding the tool by the handle. The authors found that children perseverated in holding the tool as they had been taught to, even when it was employed for a different function. Thus the authors conclude that "rather than learning about tool function (e.g., hammering), infants learn about which part of the tool is meant to be held, at least early in their exposure to a novel tool." (p. 352).

If we assume that this advantage not only influences tool use but also tool concepts, these results suggest that infants might initially categorize tools according to their manipulative features rather then their functions. However, there are good reasons to be wary of this conclusion. In this study, function and grasp were manipulated in very different ways. Children were trained on distinct grasp patterns and then presented with a tool which would allow them to use whichever grasp they had acquired (though only one grasp would solve the problem). In contrast, function was manipulated by creating two separate tasks: children were not allowed to choose which function to perform on each trial (the object acted upon did not afford both), nor were they allowed to choose which tool to perform the function with. The strongest claim that can be made on the basis of these data is that the child's knowledge of the grasp is not bound tightly to a function of the tool that emerges when the same tool is put to new uses.

The second study examines knowledge of tool movements in school-aged children (Mounoud, Duscherer, Moy & Perraudin, 2007). Mounoud and colleagues found that children between 5 and 12 can identify some pantomimes of tool use. Furthermore viewing these pantomimes facilitates subsequent identification or categorization of a picture of the tool involved in the enactment. The authors note that these results are compatible with a range of hypotheses. Among them is the possibility

that viewing the pantomimes activates the motor programs used for executing the same

action and that these motor programs are part of the conceptual representation of the tool.

However they also acknowledge the possibility that the facilitation effect reflects: 1)

direct connections between motoric and visual representations of the tool; 2) priming of

verbs that describe the pantomime and are associated with the tool; 3) activation of

abstract conceptual knowledge about the depicted action including its function and the

objects typically associated with it. In fact, Mounoud and collaborators argue for the

centrality of action representation in young children's tool concepts by invoking the

importance of goals and then functions in children's conceptualization.

From a developmental point of view, action goals are the basis on which children
apprehend the various functional properties of objects; action goals explain how children
attribute meaning to objects and actions. Once this first step in concept formation is
achieved, children will be able to select functionally equivalent elements, thus grounding
taxonomic categories.

The use of the word *action* to describe both motoric manipulations and the functions that

they serve is common in discussions of embodied cognition. However, as Mounoud and

colleagues note, neuropsychological evidence suggests that our knowledge of object

function and our knowledge of object manipulation are distinct. Apraxic patients (with

lesions in the left IPS, IPL and dorsal premotor cortex) are impaired in their knowledge

of object manipulation but retain their knowledge of object functions, while patients with

lesions in the anterior inferotemporal areas often have impaired knowledge of tool

functions but retain the ability to manipulate tools (e.g., Buxbaum & Saffran, 2002;

Buxbaum, Veramonti, & Schwartz, 2000; Sirigu, Duhamel & Poncet, 1991). The studies

that follow explore which of these two distinct kinds of information constrains the

extension of novel tool terms.

Present Studies

To investigate the content of tool concepts, we conducted a series of word extension experiments with adults, 5-year-olds and 3-year-olds. If motor information determines conceptual content then the novel label should be extended to objects that share the same motor manipulation. Such a finding would support the strong embodied view of conceptual content. Alternatively, if abstract information like the tool's function determines conceptual content, then the novel label should be extended to objects that share the same function. Comparing adults' responses with children's will allow us to see whether there is a developmental shift in the content of tool concepts.

Experiment 1

Participants

 Sixteen adults (7 men, M=22;5, range 19;3-31;5) and 24 five-year-olds (12 boys, M=5;0, range 4;5-5;6) participated in the study. All were native English speakers.

Stimuli

Two sets of practice items and five sets of critical items were developed. Each set consisted of three novel tools. For practice items, there was a standard tool with a particular motor manipulation and function (i.e., it had to be squeezed to force playdough out) and two test items. One of the test tools shared both the motor manipulation and the function of the target tool while the other shared neither. Practice tools were used to teach participants the task without biasing them to respond to either the motor manipulation or the function of the standard tool. We expected participants to always select the tool that shared both features with the target; participants who did not do so were corrected and given a second chance.

For the critical items, each set of novel tools consisted of a standard tool with a particular motor manipulation M_1 (i.e., the tool had to be swung up and down) and a particular function F_1 (i.e., to make holes in playdough) and two test tools. One test tool shared the motor manipulation M_1 (i.e., it had to be swung up and down) but had a different function F_2 (i.e., to make a noise). The other test tool shared the standard tool's function F_1 (i.e., making holes in playdough) but had a different motor manipulation M_2 (i.e., it had to be rolled by extending and retracting the arm).

All tools within a set had a similar shape and color. To ensure that our findings were not colored by preferences for particular objects, motor manipulations or functions, we counterbalanced across participants which of the test tools was the function match and which was the motor match. This was done by designing each standard tool so that it had two different functions and motor manipulations. For example, the standard tool from the above example could also be rolled (M_2) to make noise (F_2). The first test tool in the set in this case shared the function F_2 (to make a noise) but not the motor manipulation M_1 (it had to be swung) and the second test tool shared the motor manipulation M_2 (it had to be rolled) but not the function F_1 (to make holes in playdough). See Figure 1 for an example.

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Figure 1

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Table 1 lists the functions and motor manipulations for each test trial. The order of presentation of the two test tools was counterbalanced within and across participants. Thus each participant saw the function match before the motor match on half of the trials and the motor match before the function match for the other half. Similarly for each test

set, half of the participants saw the function match first and half saw the motor match first.

Table 1

Procedure

The procedures for practice trials and critical trials were identical. First, the experimenter showed the standard tool to the participant, labeling it with a novel word (i.e., "This is a *quep*"). Then she demonstrated how to use it and what it is for, naming both the motor manipulation and the function (i.e., "You roll it to make holes in playdough"). Then the experimenter demonstrated and labeled the manipulation and function of each test tool. After this, both test tools were put in front of the participant. Then the experimenter asked: "Which one is another *quep*?" After the participant pointed to one of the tools, the experimenter moved on to the next trial. All participants succeeded in choosing the correct tools on the practice trials and proceeded to the critical trials.

Results

For each participant we calculated the proportion of function choices (Figure 2). This score could range from +1 (all function matches) to 0 (all motor matches), with .5 indicating chance performance. These scores were submitted to one-sample t-tests to determine whether they deviated from chance. Adults showed a reliable preference for the test item with the same function, selecting it 93% of the time (t(15)=17, p<0.001). Five-year-olds shared this preference for the tool with the same function, selecting it 75%

of the time (t(23)=5.93, p<0.01)[3]. A direct comparison of the two groups confirmed that

adults were more likely to categorize tools based on shared function (t(35)=3.57,

p<0.005). All 16 adults and 21 of the 24 children selected more function than motor

matches ($\chi^2(1)$=16, p<.001; $\chi^2(1)$=13.5, p<.001, respectively).

Figure 2

Discussion

Both five-year-old children and adults are more likely to categorize novel tools

based on shared function rather than shared motor movement. These data suggest that

abstract conceptual information plays a greater role in the extension of tool concepts than

associated motor representations. However, five-year-olds were less likely than adults to

choose tools based on function. There are two possible explanations for this difference.

One is that children's concepts are as abstract as adults' but limitations in their attention,

memory, or understanding of the task impede their performance.

The second possibility is that five-year-olds are in transition from a more concrete

conceptual system to a more abstract one. To begin exploring this developmental

trajectory, we examined the extension of tool concepts in three-year-olds. Three-year-

olds are of interest for several reasons. First, in many word learning tasks they show a

greater reliance on concrete perceptual features than older children (e.g., Smith et al.,

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[3] This finding was replicated in an additional experiment which explored whether preference for function
persisted over a delay. Children were given an irrelevant task (to color a drawing) after the presentation of
the test tools and before they were asked the test question. Sixteen 5-year-olds participated (11 boys,
mean=4;10; range: 4;6-5;5). The children extended the novel tool terms to items with the same function on
70% of trials (t(15)=4.14, p<0.01).

1996). Second, they have limited experience using tools and know fewer tool terms than older children and adults.

Experiment 2

Experiment 2 consisted of three conditions. One condition (Exp 2c) paralleled our first experiment by examining 3-year-olds' categorization when motor movement and function were pitted against each other. The other two conditions provided a baseline by examining children's categorization when only one dimension was available. Exp 2a explored whether children would categorize tools on the basis of shared motor information in the absence of function information. Exp. 2b examined the effect of shared function in the absence of motor information. Strong performance in both conditions would validate our method, demonstrating that children are able to encode both features in this task.

Participants, Stimuli and Procedure

 A total of 48 3-year-olds were tested, 16 in each condition (23 boys, M=3;3; range 3;0-3;6). All were native English speakers.

The stimuli were identical to Exp. 1, but the procedure was slightly different. Three changes were made to ensure that the task was appropriate for this younger age group. First, children were only told one fact about each of the test tools. Second, all critical information was repeated three times. Finally, children were given the chance to manipulate the test tools.

At the beginning of each trial, the experimenter labeled the standard tool. Then she demonstrated and described its critical properties: manipulation in Exp. 2a, function in Exp. 2b and both in Exp 2c. To ensure that our young participants caught all this, it

was repeated three times. Next the experimenter introduced and demonstrated the tests

tools. In Exp. 2a, only motor information was presented. In Exp. 2b, only functions were

presented. In Exp. 2c, the experimenter demonstrated each test tool's function and

manipulation but labeled only the property that the tool shared with the standard. In all

three conditions, this information about the test tools was repeated while the child

manipulated them. Finally, before the test question, the experimenter reminded the child

about the name of the standard, its function and/or manipulation, and the labeled feature

of each test tool.

Analyses and Results

To compare performance across conditions, we coded the responses as function

matches or motor matches. In Exp. 2c this distinction is straightforward. In Exp. 2a,

selection of the non-motor match was coded as a function match, because this is the item

that would have been the function match in Exp. 2c. Similarly, in Exp. 2b non-function

matches were coded as motor matches. This allows us to compare how changes in the

information provided influence participants selection of a stable set of objects. The

proportion of function matches was analyzed as before (see Figure 3).

In Exp. 2a, children were only given information about the movement used to

employ the tool. They made reliable use of this cue, selecting the motor match for 69% of

the trials, resulting in below chance selection of the function match ($t(15)=2.96$, $p<0.01$).

In Exp. 2b, children reliably used the function information that was provided for

categorization, selecting the function match on 64% of the trials ($t(15)=2.80$, $p<0.01$).

Thus 3-year-olds clearly encode both function and motor information and can use both

features in categorization.

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Figure 3

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Exp. 2c pitted function against motor information. Here we found that 3-year-olds, like 5-year-olds and adults, showed a strong and reliable preference to categorize tools on the basis of shared function (71% of trials, t(15)=3.88, p<0.01). There was a substantial shift from Exp. 2a to Exp. 2c, verifying that adding conflicting function information overrides categorization by motor movement (t(30)=4.79, p<.001). However, there was no reliable difference between Exp. 2b and Exp. 2c, suggesting that adding competing motor information has no effect on categorization by function (t(30)=1.02, p>.3).

Discussion

These results indicate that 3-year-olds categorize tools on the basis of shared function. While this may suggest that the content of tool concepts is abstract, there is another, more perceptually based, interpretation. The children could be categorizing the tools according to the perceptual end-state brought about by their manipulation (i.e., the patterns in the playdough). These perceptual end-states were visible when the extension question was asked and may have guided responses. To explore this possibility, we tested 5-year-olds in a paradigm in which the tool's function was not perceptually accessible. These new functions were novel and imaginary (e.g., "*to know what someone is thinking*") and no observable change happened when the tool was manipulated. If children can use such functions as the basis of categorization, we can conclude that

function cannot be reduced to perceptual end-state and tool concepts must be abstract by 5 years of age.

Experiment 3

Participants, Stimuli and Procedure

Fifteen native English speaking 5-year-olds (8 boys, M=5;1; range 4;3–5;8). The stimuli for consisted of six triplets of novel tools (plus two practice sets). The tools in each pair were similar in appearance but differed in their imaginary functions and motor movements (for a list of the invisible functions, see Table 2). The procedure was identical to Exp. 1.

_____

Table 2

_____

Results

Again we calculated the proportion of function choices for each participant and submitted the scores to a one-sample t-test (Figure 2). Five-year-olds categorized based on function on 82% of trials (t(15)=4.74, p<0.001). Thirteen of the fifteen children selected more function than motor matches (χ^2(1)=8, p<.005).

General Discussion

These studies demonstrate that both young children and adults categorize novel tools based on their functions rather than the movements used to employ them This pattern is in place quite early in development. By three years of age function is so central to children's tool concepts that their use of function is uninfluenced by the presentation of conflicting information about the tool's motor manipulation (Exp. 2b and 2c). This notion

of function cannot be reduced to the perceptual end-state of the event -- by five years of age, children categorize by function even when the function is not visible (i.e., the function of 'making a wish come true' or 'knowing what someone is thinking' in Exp. 3). If we accept the common premise that conceptual content guides categorization, then these results indicate that motor information plays little or no part in the conceptual content of tool terms. Instead these findings demonstrate that function plays a central role in the conceptual content of tool terms, or that function is closely associated with some other property which plays this role (e.g., creator's intended function). Thus our findings run counter to the hypothesis suggested by the strong embodied view, namely, that motor information determines the conceptual content of tool terms.

In the remainder of this discussion we attempt to integrate these findings with two distinct literatures: 1) developmental studies on children's knowledge of tools and their extension of artifact labels and 2) studies in cognitive neuroscience on motoric activation during conceptual processing of tools.

The development of tool concepts

The conclusions of the present study may appear to be at odds with a growing literature suggesting the movement and motor experience affect children's use and understanding of tools (Barrett et al., 2007; Mounoud et al., 2007; Sommerville, Hidebrand & Crane, 2008). We see no such conflict. Clearly children have knowledge of the manipulative properties of tools from a young age: How else could they learn to use them (Barrett et al., 2007; Connolly and Dalgleish, 1989)? But that does not mean that these motoric representations provide the conceptual content of tool terms. The only prior study which links children's motoric representations to their knowledge of tool terms si

the Mounoud pantomime experiment (2007). While the authors find that action

pantomimes facilitate tool identification, they are quick to point out that this finding is

compatible with a diverse set of mechanisms. One of these possibilities is that the

pantomimes are analyzed at a functional level resulting in direct priming of the tool

concepts that are linked to these functions. By demonstrating that functions are central to

the conceptual content of tools (independent of motor patterns), our results provide

further support to this analysis.

Perhaps the strongest argument in favor of motoric tool concepts is one based on

developmental priority. As we noted in the introduction, Barrett and colleagues (2007)

have suggested that infants initially learn about the manipulative properties of tools rather

than their functions. This position is consistent with developmental theories which posit

hat concept acquisition proceeds from the concrete to the abstract and raises the

possibility that motor information continues to play a privileged role in establishing

conceptual content. However the bulk of the evidence does not support this view. First,

as we noted in the introduction, the Barrett study does not directly test whether infants

have encoded the function of the novel tool, instead it demonstrates that representations

of tool manipulation extend across functions. Infants who practice inserting a tool while

holding onto a loop, continue holding the loop in a rotation task, but that does not mean

that they did not learn that the tool was initially used for insertion. In fact, more direct

assessments have consistently found evidence that children encode functional

information by about one year of age (Madole, Oakes & Cohen, 1993; Booth & Waxman,

2002; Träuble & Pauen, 2007). Träuble and Pauen's study is particularly relevant

because it rules out the possibility that what appears to be functional encoding is actually

motoric: 11-12 month old infants were presented with objects that could either be categorized in terms of global similarity or similarity of a particular functionally relevant part. Categorization was assessed by manual habituation. Children who saw a demonstration of the function of the part categorized on that basis, while uninitiated children favored global similarity. Critically a control group of children who observed the objects being manipulated in the same way--but without producing the function--also categorized based on global similarity.

Our findings demonstrate that functional information continues to play a central role in categorization in young children and adults. These results are consistent with prior studies using the word extension task in young children. In experiments in which perceptual similarity is equated, function guides the extension of novel artifact labels in children as young as two (Kemler Nelson et al., 2000ab). However, these previous studies have one clear limitation: function was manipulated without regard to the motor content of the action. In the ordinary course of events, this would lead either to a systematic confound between function and motor movement (when the function is demonstrated) or to the absence of motoric information (when the function is merely described). Thus the present study goes beyond the prior work by demonstrating that function continues to guide categorization even when it is pitted against motoric similarity.

Curiously our findings suggest that motoric information may be less central to children's tool concepts than shape is. Differences in shape clearly interfere with children's ability to extend artifact terms on the basis of their function. In fact, when shape is pitted against function, young children sometimes prefer to categorize on the

basis of shape (see e.g., Landau, Smith, & Jones, 1998; Smith et al., 1996). The

interpretation of this data pattern is controversial: Some researchers see it as evidence of

a shift from concrete to abstract (Smith et al., 1996) while others suggest that it reflects

children's knowledge that form usually reflects the intended function of an object

(Kemler Nelson et al., 2000a). In contrast, we find no evidence that motor information

competes with function during word extension. Three year olds preference for functional

extension was as strong in the presence of conflicting motoric cues as it was in their

absence.

How can we account for motor activations in tool tasks?

The present studies were motivated by the robust observation that brain regions

associated with movement and motor imagery are active during conceptual tool tasks.

These findings raised the possibility that motoric representations provide the cognitive

content of tool terms. Perhaps motor regions become active because they contain the

representations which individuate and determine the extension of tool concepts. The

present findings are clearly rule out this possibility. Both adults and young children

systematically extend tool terms according the function of a tool rather than the way in

which it is manipulated.

So how do we account for the activation of motor regions during tool processing?

Our findings are consistent with a wide range of possibilities. Three further

considerations provide additional constraint.

First, motor activations emerge across a wide range of tasks and stimuli including

viewing pictures of tools, naming tool sounds, spontaneously generating tool names, and

making lexical decisions for tool terms (Lewis, Brefczynski, Phinney, Janik & DeYoe,

2005 Kiefer, 2005; Vitali et al., 2005). Thus these activations cannot be attributed to a single response task or stimulus modality and are unlikely to reflect strategic behaviors (such as explicit motor imagery). They appear to be an intrinsic part of the neural processes invoked when we think about tools.

Second, evidence from both neuroimaging and patient studies demonstrates that the processing streams are involved in representation of motoric and functional knowledge are partially distinct. For example, Canessa and colleagues found that when people compared tools according to their shared function, lateral anterior inferotemporal cortex was active. But when tools were compared according to shared motor manipulation greater activation was observed in motion-sensitive including left-IPS and dorsal premotor cortex (Canessa, Borgo, Cappa, Perani, Falini, Buccino, Tettamanti & Shallice, 2008). The same pattern emerges in patient studies: lesions in dorsal stream regions which are implicated in tool processing are associated with apraxia, a deficit in motoric knowledge, while anterior infereotemporal lesions are associated with deficit in functional knowledge (Buxbaum & Saffran, 2002; Buxbaum et al., 2000; Sirigu et al., 1991).

Third, the pattern of deficits in apraxic patients suggest that activation of motor regions is not necessary for performing many of the conceptual tasks in which motor activations are typically observed. Apraxic patients can often name pictures of objects that they cannot use (see e.g., Ochipa et al., 1989) and sort these objects based on their functional properties (Buxbaum & Saffran, 2002), suggesting that activation of motoric representations in not necessary lexical and conceptual processing of tool terms (Mahon & Caramazza, 2009). However, this does not mean that motor representations are not

useful for tool identification. Mahon and colleagues tested patients who had temporal

and frontal lesions (Mahon et al., 2007). They found that deficits in object use were

correlated with deficits in object identification, but only for patients who also had parietal

lesions. They argue that in the context of damaged semantic system, motor information

could facilitate object identification.

Taken in concert, these findings suggest that activation of motor areas during tool

processing reflect motoric representations that are strongly associated with particular

tools but do not define them.   As Mahon and Caramazza (2008) note, many cognitive

processes are characterized by the almost simultaneous activation of multiple levels of

representation. For example, during word recognition the activation of word forms

(phonological or orthographic) is immediately followed by the activation of word

meanings. This begins long before the word is uniquely identified. After hearing just a

few phonemes of a word, we begin accessing the semantic associates of words that begin

with those phonemes (Yee & Sedivy, 2006).   As a consequence, semantic manipulations

can influence performance on tasks which in principle could be carried out solely on the

basis of the word's phonological representation. For example, semantic priming speeds

up both lexical decisions (Meyer & Schvaneveldt, 1976) and word naming (Frost, Katz &

Bentin, 1987). But no one would argue that phonological or orthographic representations

are composed of or grounded in semantic representations (or that the content of semantic

representations is phonological). Instead most theorists posit that the strong association

between meaning and phonological form leads the semantic representation to become

active whenever the phonological representation is processed. Similarly, we would argue

that motor programs are not the content of tool concepts but instead are strongly

associated with these concepts. Over time this strong association ensures that when we retrieve a tool concept the motor representation is quickly activated as well.

Final Words

Barsalou (2008) notes that the study of concepts has progressed along two divergent paths. Cognitive science has used linguistic analysis, inductive inference and word extension to demonstrate the surprising abstraction of everyday concepts from early in development (see e.g., Carey, 2009; Gelman, 2003). Meanwhile, cognitive neuroscience has produced equally convincing demonstrations that perceptual and motor systems are rapidly engaged during conceptual tasks.   The present study sought to bridge these paths by using the methods of developmental cognitive science to explore a theoretical proposal from cognitive neuroscience.

Imagining studies suggest that motor areas are often active during conceptual tool tasks, raising the possibility that cognitive content of tool terms is motoric. Our results demonstrate that this is false. Both adults and young children systematically categorize tools according to their function and not the movements used to employ them. These results are consistent with prior studies demonstrating that function plays a critical role in children's artifact concepts. Our results also constrain the interpretation of the imaging studies. While motor areas are clearly active in tool tasks, the content of tool concepts is not motoric. This does not rule out the possibility that motoric representations are facilatory or even necessary for performing many tool tasks; it simply suggest that we need to explore other hypotheses about the role that they play.

Acknowledgements

Figure 1. Example of critical trial Experiment 1: the function and motor manipulation of
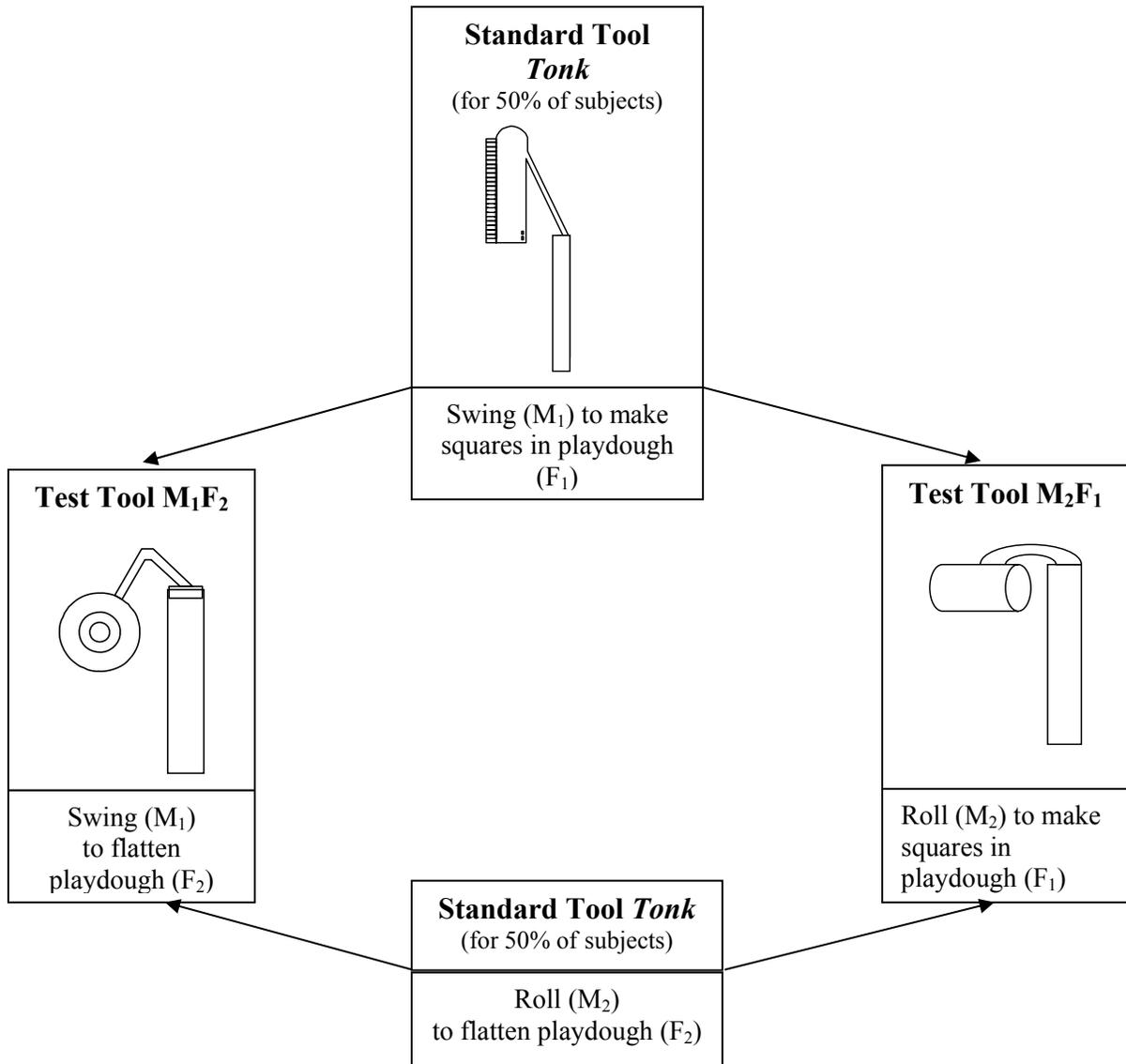
the standard was counter-balanced between subjects.

Standard Tool
Tonk
(for 50% of subjects)

Swing (M_1) to make
squares in playdough
(F_1)

Test Tool M_1F_2

Swing (M_1)
to flatten
playdough (F_2)

Test Tool M_2F_1

Roll (M_2) to make
squares in
playdough (F_1)

Standard Tool *Tonk*
(for 50% of subjects)

Roll (M_2)
to flatten playdough (F_2)

Table 1. List of functions and motor manipulations for the critical trials of Experiment 1.

Standard Tool		Name	Test Tool 1	Test Tool 2
F_1M_1	F_2M_2			
A1: Roll to print butterflies	A2: Stamp to cut circles in playdough	Lat	Stamp to print butterflies	Roll to cut circles in playdough
B1: Push with two hands to make patterns in playdough	B2: Swing to make a noise	Zeft	Push with two hands to make a noise	Swing to make patterns in playdough
C1: Roll sideways to make squares in playdough	C2: Tap to make playdough flat	Tonk	Tap to make squares in playdough	Roll sideways to make playdough flat
D1: Press a button to make noise	D2: Slam to cut a star	Birt	Press a button to cut a star	Slam to make a noise
E1: Rock to make playdough flat	E2: Press to cut triangles	Fex	Press to make playdough flat	Rock to cut triangles

Figure 2. Proportion of Tools Extended on the Basis of Shared Function for Adults and 5-year-olds in Experiments 1 and 3.
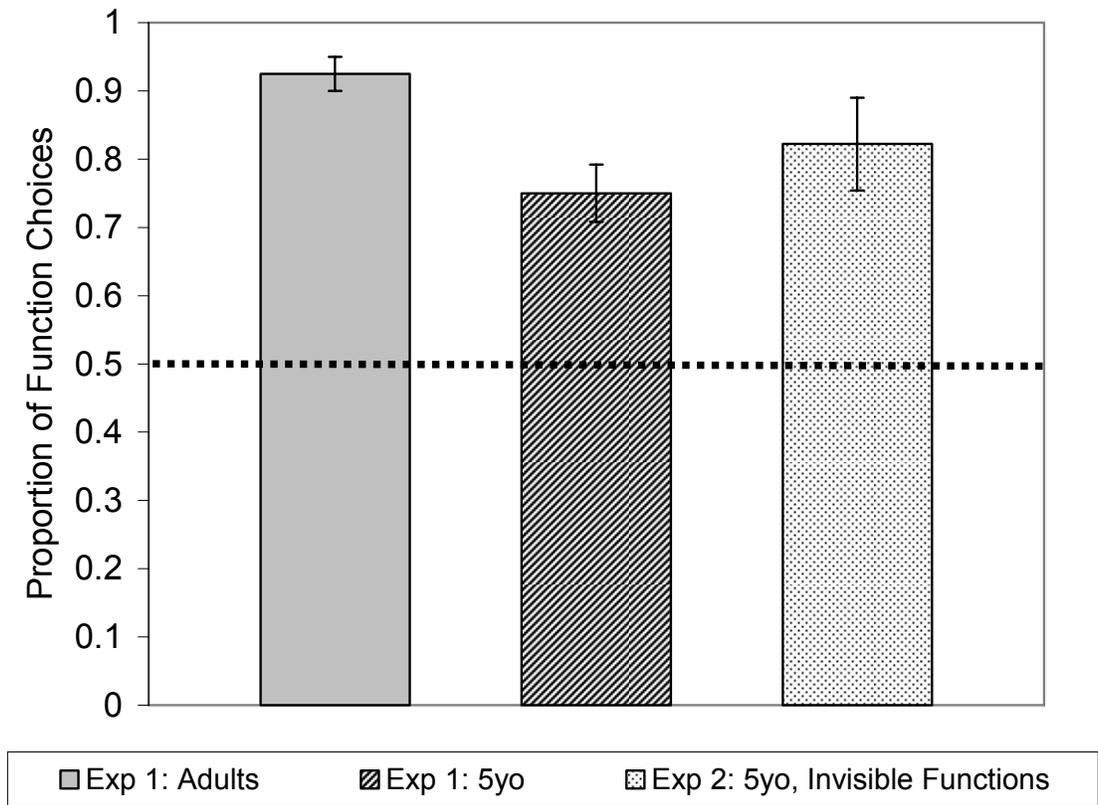
Figure 3. Proportion of Function Choices (or Non-Motor choices) for 3-year-olds in
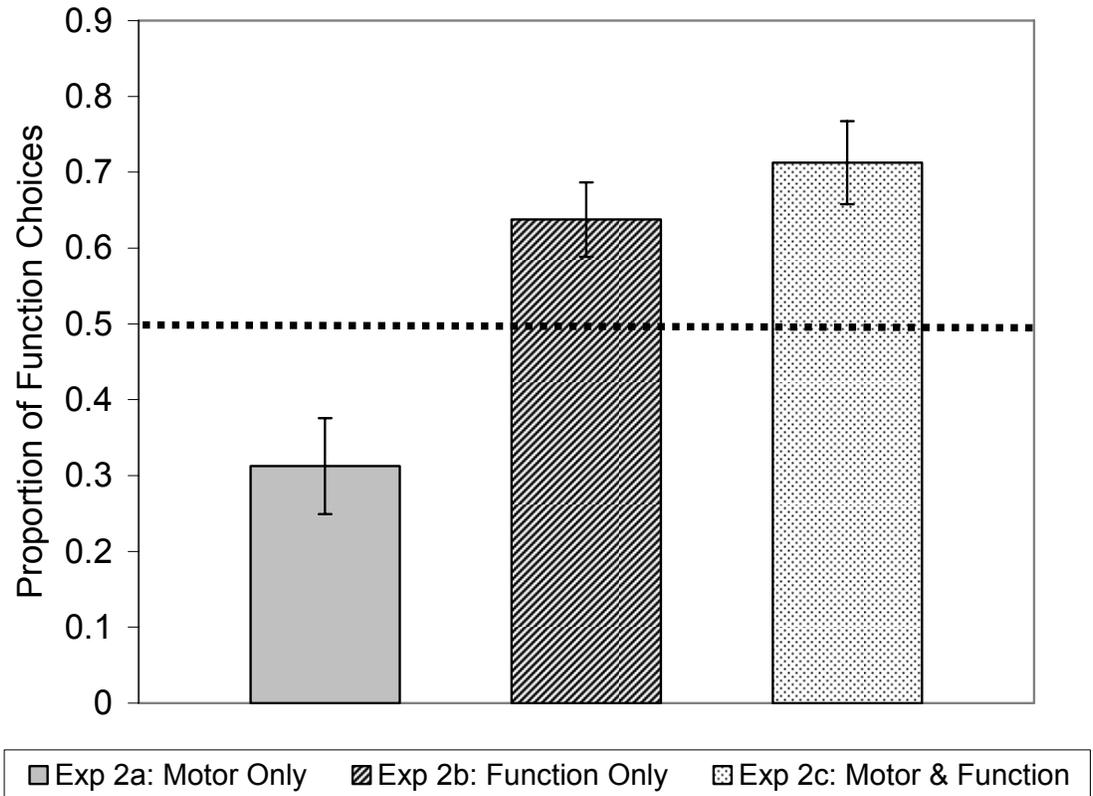
Experiment 2.

Table 1. Invisible functions and visible motor manipulations for Experiment 3.

Standard Tool		Name	Test Tool 1	Test Tool 2
F_1M_1	F_2M_2			
A1: Roll to make it rain	A2: Stamp to make rocks soft	Lat	Stamp to make it rain	Roll to make rocks soft
B1: Push with two hands to heat up water	B2: Swing to make a wish come true	Zeft	Push with two hands to make a wish come true	Swing to heat up water
C1: Roll to make toys invisible	C2: Tap to make plants grow	Tonk	Tap to make toys invisible	Roll to make plants grow
D1: Wave in a circle to make people fall asleep	D2: Swing to make a chicken lay an egg	Dev	Wave in a circle to make a chicken lay an egg	Swing to make people fall asleep
E1: Rock to make juice salty	E2: Press to make bread	Fex	Press to make juice salty	Rock to make bread
F1: Hop to clean up a mess	F2: Squeeze to find an answer to a riddle	Vilk	Hop to answer a riddle	Squeeze to clean up a mess

References

Barsalou, L.W. (2008). Cognitive and neural contributions to understanding the

conceptual system. *Current Directions in Psychological Science, 17,* 91-95.

Barsalou, L., Simmons, W., Barbey, A., & Wilson, C. (2003). Grounding conceptual

knowledge in modality-specific systems. *Trends in Cognitive Sciences, 7,* 84-92.

Bedny, M., Caramazza, A., Grossman, E., Pascuale-Leone, P, & Saxe, R. (2008).

Concepts are more than percepts: The case of action verbs. *Journal of*

Neuroscience, 28(4), 11347-11353.

Booth, A., & Waxman, S. (2002). Object names and object functions serve as cues to

categories for infants. *Developmental Psychology, 38*, 948–957.

Boronat, C., Buxbaum, L., Coslett, H., Tang, K., Saffran, E., Kimberg, D. & Detre, J.

(2005). Distinctions between manipulation and function knowledge of objects:

Evidence from functional magnetic resonance imaging. *Cognitive Brain*

Research, 23(2-3), 361-373.

Braswell, G. S., Rosengren, K. S., Pierroutsakos, S. L. (2007). Task constraints on

preschool children's grip configurations during drawing. *Developmental*

Psychobiology, 9(2), 216-225

Buxbaum L. & Saffran E. (2002). Knowledge of object manipulation and object function:

dissociations in apraxic and nonapraxic subjects. *Brain and Language, 82,* 79-

199.

Buxbaum, L., Veramonti, T., & Schwartz, M. (2000). Function and manipulation tool

knowledge in apraxia: Knowing 'what for'but not 'how'. *Neurocase,6*(2), 83-97.

Canessa, N., Borgo, F., Cappa, S.F., Perani D., Falini, A., Buccino, G., Tettamanti, M. & Shallice, T. (2008). The different neural correlates of action and functional knowledge in semantic memory: An fMRI study. *Cerebral Cortex, 18,* 740-751.

Carey, S. (2009). *The Origins of Concepts,* New York: Oxford University Press.

Chao, L.,Haxby, J., & Martin, A. (1999). Attribute-based neural substrates in temporal cortex for perceiving and knowing about objects. *Nature Neuroscience, 99, 2* (10), 913.

Connolly, K., & Dalgleish, M. (1989). The emergence of a tool-using skill in infancy. *Developmental Psychology, 25,* 894-912

Decety, J. (1996). The neurophysiological basis of motor imagery. *Behavioural Brain Research, 77*(1), 45-52.

Dewar, K., & Xu, F. (2007). Do 9-month-old infants expect distinct words to refer to kinds? *Developmental Psychology, 43*(5), 1227-1238.

Dewar, K., & Xu, F. (2009). Do early nouns refer to kinds or distinct shapes? Evidence from 10-month-old infants. *Psychological Science, 20*(1).

Diesendruck, G., Markson, L., & Bloom, P. (2003). Children's reliance on creator's intent in extending names for artifacts. *Psychological Science, 14*(2), 164-168.

Flavell, J.H., Miller, P.H., & Miller, S.A. (2002). *Cognitive development* (4th ed.). Upper Saddle River, NJ: Prentice Hall.

Fodor, J. (1998). *Concepts: Where cognitive science went wrong.* New York, NY, US: Clarendon Press/Oxford University Press.

Frost, R., Katz, L., & Bentin, S. (1987). Strategies for visual word recognition and orthographical depth: A multilingual comparison. *Journal of Experimental Psychology: Human Perception and Performance, 13*(1), 104-115.

Gallese, V., & Lakoff, G. (2005). The brain's concepts: The role of the sensory-motor system in conceptual knowledge. *Cognitive Neuropsychology, 22*(3), 455-479.

Gelman, S. A. (2003). *The essential child: Origins of essentialism in everyday thought.* New York: Oxford University Press.

Gentner, D. (1978). What looks like a jiggy but acts like a zimbo? A study of early word meaning with artificial objects. *Papers and Reports on Child Language Development, 15,* 1-6.

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin* and *Review*, *9*, 558-565.

Glenberg, A., & Kaschak, M. (2005). Language is grounded in action. In L. Carlson, & E. van der Zee (Eds.), *Functional features in language and space: Insights from perception, categorization, and development.* (pp. 11-24). New York, NY, US: Oxford University Press.

Gombert, G.E. (1992). Metalinguistic Development. Chicago: University of Chicago Press.

Johnson-Frey, S. (2004). The neural basis of complex tool use in humans. *Trends in Cognitive Sciences, 8,* 71-78.

Kan, I. P., Kable, J. W., Van Scoyoc, A., Chatterjee, A. & Thompson-Schill, S. L. (2006). Fractionating the left frontal response to tools: Dissociable effects of motor

experience and lexical competition. *Journal of Cognitive Neuroscience, 18*(2), 267-277.

Kellenbach M., Brett M. & Patterson K. (2003). Actions speak louder than functions: the importance of manipulability and action in tool representation. *Journal of Cognitive Neuroscience, 15,* 30-46.

Kemler Nelson, D. G.,Russell, R. & Duke, N. (2000a). Two-year-olds will name artifacts by their functions. *Child Development, 71*(5), 1271-1288.

Kemler Nelson, D. G., Frankenfield, A., Morris, C. & Blaire, E. (2000b). Young children's use of functional information to recognize artifacts: Three factors that matter. *Cognition, 77*, 133 – 168.

Landau, B., Smith, L. and Jones, S., (1988). The importance of shape in early lexical learning. *Cognitive Development, 3,* 299–321.

Madole, K., Oakes, L., & Cohen, L. (1993). Developmental changes in infants' attention to function and form-function correlations. *Cognitive Development, 8*, 189–209.

Mahon, B. & Caramazza, A. (2008). A critical look at the embodied cognition hypothesis and a new proposal for grounding conceptual content. *Journal of Physiology – Paris, 102*, 59-70.

Mahon, B., Milleville, S., Negri, G., Rumiati, R., Caramazza, A., & Martin, A. (2007). Action-related properties shape object representations in the ventral stream. *Neuron, 55*(*3*), 507-520,

Markman, E., & Hutchinson, J. (1984). Children's sensitivity to constraints on word

meaning: Taxonomic versus thematic relations. *Cognitive Psychology, 16*(1), 1-

27.

Martin, A. (2007). The representation of object concepts in the brain. *Annual Review of

Psychology, 58*, 25-45.

Meyer, D., & Schvaneveldt, R. (1976). Meaning, memory structure, and mental

processes. *Science*, *192*(4234), 27-33.

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review of

Neuroscience, 27*, 169-192.

Rosenbloom, L., & Horton, M. E.1971. The maturation in fine prehension in young

children. *Dev. Med. Child Neurol. 13*, 3–8.

Sirigu A, Duhamel JR, Poncet M. 1991. The role of sensorimotor experience in object

recognition: A case of multimodal agnosia. *Brain, 114(6),* 2555-2573.

Smith, L. & Gasser, M. (2005) The Development of Embodied Cognition: Six Lessons

from Babies. *Artificial Life,* 1113-30

Smith, L. B., Jones, S., & Landau, B. (1996). Naming in young children: a dumb

attentional mechanism? *Cognition, 60,* 143-171.

Soja, N., Carey, S., & Spelke, E. (1991). Ontological categories guide young children's

inductions of word meaning: Object terms and substance terms. *Cognition, 38*(2),

179-211.

Träuble, B. & Pauen, S. (2007). The role of functional information for infant

categorization. *Cognition, 105(2),*. 362-379.

Vitali, P., Abutalebi, J., Tettamanti, M., Rowe, J., Scifo, P., Fazio, F., et al. (2005).

    Generating animal and tool names: An fMRI study of effective connectivity.

    Brain and Language, 93(1), 32-45.

Weisberg, J., van Turennout, M., & Martin, A. (2007). A neural system for learning

    about object function. *Cerebral Cortex, 17*(3), 513-521.

Yee, E., & Sedivy, J. (2006). Eye Movements to Pictures Reveal Transient Semantic

    Activation During Spoken Word Recognition. *Journal of Experimental*

    Psychology: Learning, Memory, and Cognition, 32(1), 1-14.