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Action Alters Shape Categories

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Abstract

Two experiments show that action alters the shape categories formed by 2-year-olds. Experiment 1 shows that moving an object horizontally (or vertically) defines the horizontal (or vertical) axis as the main axis of elongation and systematically changes the range of shapes seen as similar. Experiment 2 shows that moving an object symmetrically (or asymmetrically) also alters shape categories. Previous work has shown marked developmental changes in object recognition between 1 and 3 years of age. These results suggest a role for action in this developmental process.

Keywords: Shape; Object recognition; Action; Embodiment; Categories; Development

1. Introduction

If we used chairs, not to sit on, but to tame lions, would we see their shapes differently? Much research is based on the assumption that people recognize and categorize objects by their visual shape. The contentious and unsolved theoretical problem is the proper psychological definition of object shape (Edelman & Intrator, 2003; Hummel, 2001) The experiments reported in this article suggest that that definition may have developmental roots outside of vision proper, in how people hold, move, and act on objects. Three considerations motivate the specific experiments.

1.1. Shape is a developmental product of category learning

Although common objects seem to be categorized by shape, real instances of real categories are, in fact, not exactly the same shape. Rocking chairs, desk chairs, and stuffed living-room chairs differ dramatically in aspects of shape—in their curves, their angles, in their number of parts. Chairs have the same shape only under some minimalist category-relevant descrip-

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tion—a horizontal surface (on which to sit) properly aligned with a vertical surface (to support one's back). To solve this problem, theories of human object recognition and algorithms for the recognition of objects by machines often include a role for category learning (e.g., Duvdevani-Bar & Edelman, 1999; Ullman, 1996). The implication is that category-relevant descriptions of object shape are not a priori determinants of object categories but rather the developmental product of forming those categories.

Recent developmental data support this idea. During the period from 1 to 3 years of age, children acquire names for common object categories, and they also shift from more feature-based to more global-shape-based object recognition (see, for example, Jones & Smith, 2004; Nelson, 1972; Quinn, 2004; Rakison & Cohen, 1999). In one study (Smith, 2003), young children were presented with richly detailed and typical instances of common object categories, or with minimalist three-dimensional representations of these same things. These minimalist representations were made from three to four geometric volumes aligned in the proper spatial arrangement. The results showed dramatic developmental change linked to children's knowledge of common object categories. Two-year-olds who knew relatively many object categories for their age recognized the minimal shape representations as well as they did the richly detailed ones. In contrast, same-aged children who did not know as many categories did not recognize the minimal shapes at all, even though they recognized the richly detailed versions as well as the more advanced children. Thus there seems to be a link between learning object categories and learning a minimalist description of object shape, the kind of description that would allow for the immediate recognition of a wide variety of instances of a category. In support of this second idea, a second experiment (Smith, 2003) showed that the more advanced 2-year-olds were able to recognize minimalist versions of even novel objects. Children thus appear to be learning not just the category-relevant shapes of specific things, but they are also learning to describe the shape of anything in a category-relevant way.

1.2. Action is also a good candidate for teaching category-relevant aspects of shape

As theorists from a variety of perspectives have noted, there is a causal link between shape and function (e.g., Gelman & Bloom, 2000; J. J. Gibson, 1966). It is because chairs have horizontal and vertical surfaces that we can sit on them with back support, and thus the seats and backs of chairs are more defining of "chair-shape" than the curve of the legs or the presence of arms. A role for action is also suggested by growing evidence that our habitual manner of acting on an object is part of the memory for that object, such that the visual recognition of a thing automatically activates the actions associated with it (see Creem & Proffitt, 2001; Ellis & Tucker, 2000; Glenberg, Robertson, Kaschak, & Malter, 2003). Other evidence indicates that object-related actions and object identification rely on common brain regions (e.g., Faillenot, Toni, Decety, Gregoire, & Jeannerod, 1997; Grezes & Decety, 2001). Might not action, then, play a formative role in the representation of an object's shape and perhaps also in creating the very dimensions of shape across which objects are categorized and compared?

1.3. Axes of elongation and symmetry are important to object recognition

One way action may inform a category-relevant description of object shape is by determining the psychologically relevant axes of the object. Several influential theories emphasize the importance of axes of elongation and symmetry for parsing and comparing shapes (Biederman, 1987; Marr & Nishihara, 1992). Further, there is considerable evidence that shape—and perceived axes of elongation and symmetry—depend on (and also influence) the perceived frame of reference (Quinlan & Humphreys, 1993; Rock, 1973; Sekuler, 1996; Sekuler & Swimmer, 2000). For example, the same pattern can be seen as a square or a diamond, depending on how one assigns the reference frame and the main axis of symmetry (Rock, 1973). Perceived axes of elongation and symmetry are also influenced by motion (Bucher & Palmer, 1985; Rock, 1973; Sekuler & Swimmer, 2000). Adults are biased to see both the main axis of symmetry and the main axis of elongation as parallel to the path of movement (Morikawa, 1999; Sekuler & Swimmer, 2000).

Action, how we hold and move objects as opposed to how we see them move, has not been systematically investigated in this regard (but see E. J. Gibson, 1969; Turvey, Burton, Amazeen, Butwill, & Carello, 1998). The two experiments pursue this issue by studying how action influences 2-year-olds' categorization of three-dimensional objects. Young children were specifically chosen as participants to study the role of action during what appears to be the formative period for category-relevant descriptions of object shape.

2. Experiment 1

Imagine that you are given the three-dimensional object in Fig. 1A and are told that it is "a wug." You hold it in one hand, moving your arm and the object up and down. Then while your arms are at rest, you are presented with the two objects in Fig. 1B and asked which of these is also a wug. The conjecture is that you would choose the vertically extended object because you had moved the exemplar along a vertical path. This was the task presented to children.

2.1. Method

2.1.1. Participants

Children (65 girls, 55 boys) between 24 and 35 months of age (mean 30 months) participated, half in a forced-choice version and half in a yes–no version of the task. Within each version, children were randomly assigned to one of five conditions. There were two action conditions, horizontal and vertical, and also three no-action conditions, horizontal, vertical, and stationary. Children were tested in the laboratory, with the parent present. Parents were instructed that the task had no right or wrong answers and not to name or label any objects or to encourage any actions or choices. All sessions were videotaped to ensure that parents complied. Two children were replaced because of parental interference.

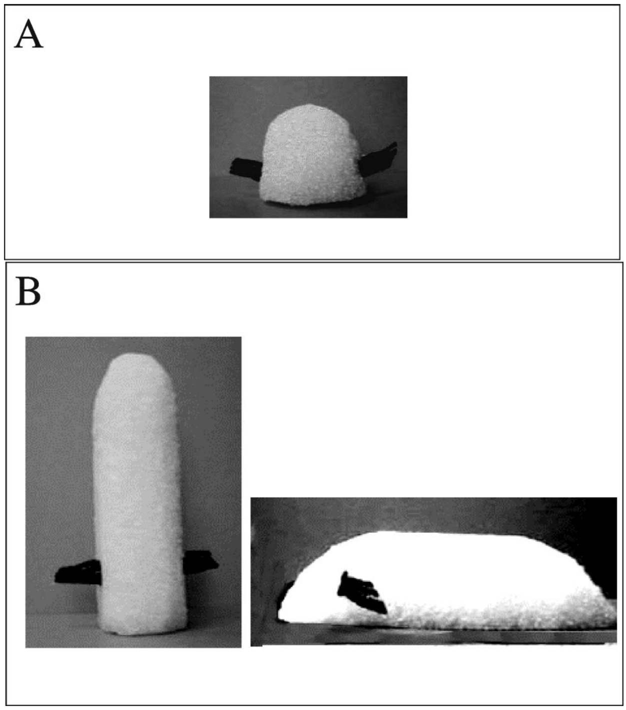

Fig. 1. The exemplar (A) and two of the test objects (B) used in Experiment 1.

2.1.2. Stimuli

Fig. 1 shows the exemplar and two of the test objects. The exemplar had a base diameter of 6 cm and a height of 6 cm. Three vertically extended test objects had the same base but differing heights of 8 cm (V1), 12 cm (V2), or 16 cm (V3). Three horizontally extended test objects had heights of 6 cm; the base of these test objects varied progressively from a circle to ellipse with major diameters of 8 cm (H1), 12 cm (H2), and 16 cm (H3). These objects were carved from white Styrofoam with black protrusions on the sides for added interest. A meter-wide by meter-tall wooden backdrop with grass painted along the bottom and a tree on the right side was used to guide the actions. For warm-up, the experimenter used a toy flower, bunny, car, and apple.

2.1.3. Forced-choice procedure

The forced-choice procedure began with a warm-up task to help children understand the test trials. The child was presented with two well-known objects, for example, the flower and bunny, placed on the table approximately 20 cm apart. The child was asked, "Where is the bunny? Show me the bunny?" Children were helped to make this first response if they did not do so immediately and warm feedback was provided for all correct responses. This was repeated with the experimenter varying the requested object until the child responded correctly on three consecutive trials. All children did so within eight warm-up trials.

Immediately after the warm-up trials, the main experiment began with the priming event. The experimenter and child stood on one side of a table facing the backdrop. The experimenter introduced the exemplar and told the child "This is a wug." In the two action conditions, the experimenter then took the exemplar and moved it the full length along the grass (in the horizontal condition) or along the tree (in the vertical condition). The child was then asked to take the "wug" and move it in the same way as the experimenter. In both action conditions, the child held the object in the same way, with the palm in a vertical orientation with the fingers wrapped around the exemplar. The experimenter helped the child if necessary and made sure the child moved the object the full length back and forth across the path three times (i.e., six lengths). The experimenter then removed the exemplar and placed two test objects on the table, asking the child, "Where is the wug? Show me the wug." No feedback was provided on test trials.

The procedures in the no-action horizontal and vertical conditions were the same, except the experimenter never asked the child to move the object. After the initial demonstration of the action, the experimenter asked the child to watch as the experimenter moved the exemplar back and forth three more times. In the no-action–no-movement condition, the experimenter merely introduced the exemplar and set it on the table, naming it several times.

The exemplar was removed from sight after these priming events, and a series of 12 test trials (presented in one of two random orders) followed. These included 4 each of three contrasts: H1 versus V1, H2 versus V2, and H3 versus V3. Halfway through testing, the experimenter repeated the priming event appropriate to the condition and then removed the exemplar before resuming the test trials.

2.1.4. Yes–no procedure

The yes–no procedure also began with warm-up trials. The child was presented with one warm-up object at a time and then asked if it could be called by a certain name. These trials were arranged so that the required answer could be a "yes" or a "no." For example, the experimenter might present the child with the apple and ask, "Is this an apple?" (the child should say "yes"), and on the next trial, the experimenter might present the child with the bunny and ask, "Is this a car?" (the child should say "no"). Children were given feedback. After a child answered three consecutive questions correctly, the main experiment began with the priming event. The procedure was identical to that of the forced-choice version except during the test trials. Under this procedure, children were queried about each of the six test objects individually, with the experimenter asking of each test object, "Is this a wug?" No feedback was provided. Each test object was queried three times for 18 total trials. Children were required to pass the warm-up procedure in 10 trials and to also answer "no" at least twice during the testing trials. Four children failed to meet these criteria and were replaced.

Each version of the experiment took approximately 30 min.

2.2. Results and discussion

Fig. 2 shows the proportion of times children chose the horizontally extended test object over the vertically extended one in the forced-choice task. In the two action conditions, children chose the horizontally extended test object when they had moved the exemplar along a horizontal path but chose the vertically extended one when they had moved the exemplar along a vertical path, as indicated by a significant main effect of direction, $F(1, 22) = 53.01$, $p < .001$. There was also an interaction between direction and test contrast, $F(2, 44) = 3.44$,

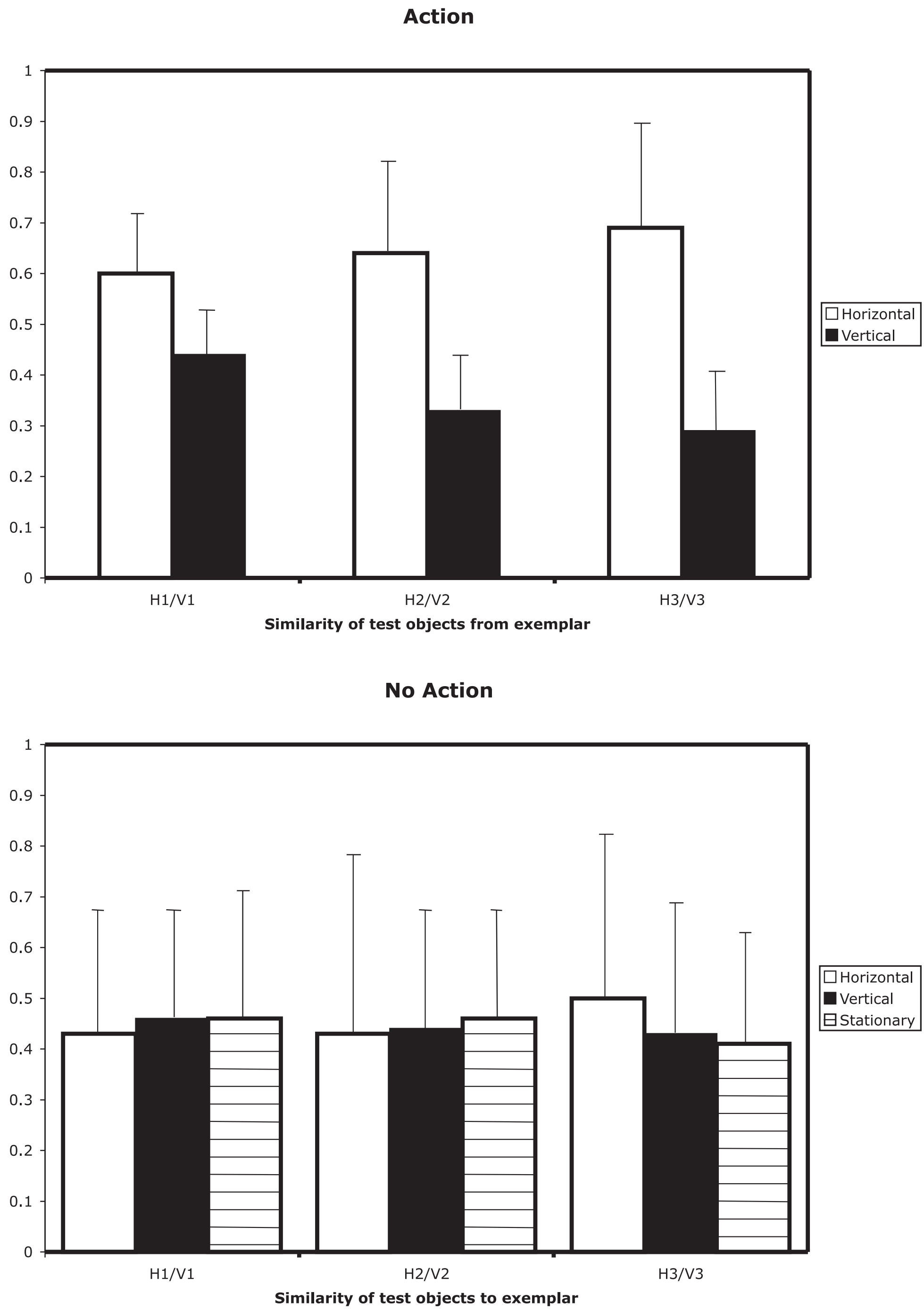

Fig. 2. Mean proportion choices of the horizontally extended test object as a function of the similarity of the contrasting test objects to the exemplar in the two Action and three No Action conditions in the Forced-Choice procedure in Experiment 1.

$p < .05$. Not surprisingly, perhaps, in this forced-choice procedure children had some difficulty choosing between two alternatives that differed little in their horizontal and vertical extent from each other and that also differed little from the exemplar. Still, the effect of action is reliable for all contrasts (Tukey honestly significant difference test, .05). Children's choices in the three no-action conditions did not differ from chance or from one another. Thus, in the two conditions in which children watched the experimenter move the exemplar horizontally or vertically, there were no systematic directional effects. Many individual children chose in a directionally consistent way (i.e., preferring the horizontally or vertically extended objects), but their preferences were not related to condition. The forced-choice procedure forces children to choose between two alternatives—both of which or neither of which—might be seen as good category members. The task thus provides a measure of the relative importance of vertical versus horizontal extension, and the results show that the relative importance depends on the child's actions.

The yes–no procedure, in contrast, assesses the perceived similarity of each test object to the exemplar singly, and thus the child is not forced by task structure to include or exclude any test object from the category. Fig. 3 shows the proportion of "yes" responses (the test object is a wug) in this task. Again, only in the action conditions was there a directional effect. More specifically, in the action conditions there was an interaction between the direction of the action and magnitude of vertical–horizontal extent, $F(2, 44) = 9.48$, $p < .001$, between the horizontal–vertical extension of the test object and magnitude of that extent, $F(2, 44) = 8,72$, $p < .001$, and between direction, horizontal–vertical extension, and magnitude of that extent, $F(2, 44) = 10.32$, $p < .001$. That is, children in the horizontal action condition said "yes" more to the horizontally than to the vertically extended test objects, and children in the vertical condition said "yes" more to the vertically extended than to the horizontally extended test objects, and these effects were greater for the test objects of intermediate similarity to the exemplar (Tukey honestly significant difference test, .05). In brief, children are more likely to include test objects that differ by smaller than by greater amounts from the exemplar in the category, but directional action broadens the magnitude of allowable within-category differences that are congruent with the direction of action. In the no-action conditions, there was only a main effect of magnitude of vertical–horizontal extent, $F(2, 66) = 8.97$, $p < .001$.

The two task procedures impose very different task demands (choosing the "better" of two alternatives versus making individual decisions about the inclusion or noninclusion of an object). Yet both indicate that action strongly influences the range of shapes taken as similar. These effects obtain only in the conditions in which children act on objects and not in the conditions in which they watch the experimenter perform the same actions. This fact constrains possible explanations as will be considered in the General Discussion.

3. Experiment 2

Experiment 2 demonstrates the generality of the phenomenon by examining the case of symmetry.

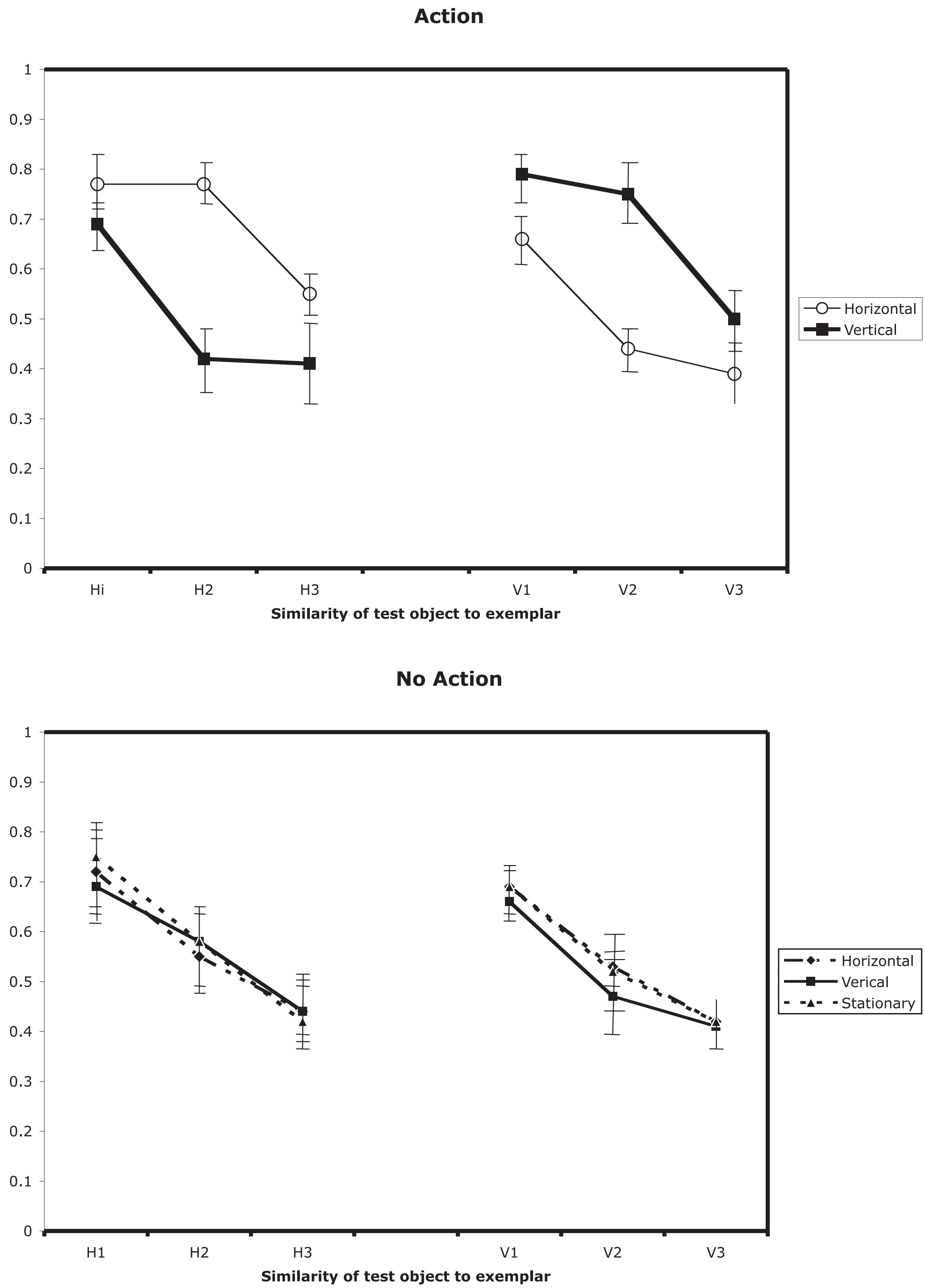

Fig. 3. Mean proportion "yes" responses as a function of the similarity of the test objects to the exemplar in the two Action and three No Action conditions in the yes–no procedure in Experiment 1.

3.1. Method

3.1.1. Participants

Children (60 girls, 60 boys) between the ages of 24 and 34 months, (mean age 30 months) participated, half in a forced-choice version and half in a yes–no version. None had participated in Experiment 1. Three children failed to meet the criteria for inclusion in the yes–no procedure and were replaced.

3.1.2. Stimuli and procedure

All aspects of the design and procedure were identical to Experiment 1, with the exception of the stimuli and the actions. Fig. 4 shows the exemplar and test objects. The exemplar was 16 cm long at its base and 3 cm deep with two "bumps" on each end, one 6.5 cm high, the other 4.5 cm high, and a height of 2.5 cm at the midpoint between them. The test objects were arranged in pairs ordered by their overall similarity to the exemplar: A1 versus S1, A2 versus S2, and A3 versus S3. The A member was less symmetric, and the *S* member was more symmetric than the exemplar. All stimuli were carved from Styrofoam and painted purple.

For the asymmetric action, the exemplar was held in one hand by the end with the smaller bump and moved in a linear motion forward and backward. For the symmetric action, the exemplar was held by two hands, one on each bump and rotated back and forth. In the no-action stationary condition, the experimenter introduced the exemplar by holding it flat on the palm

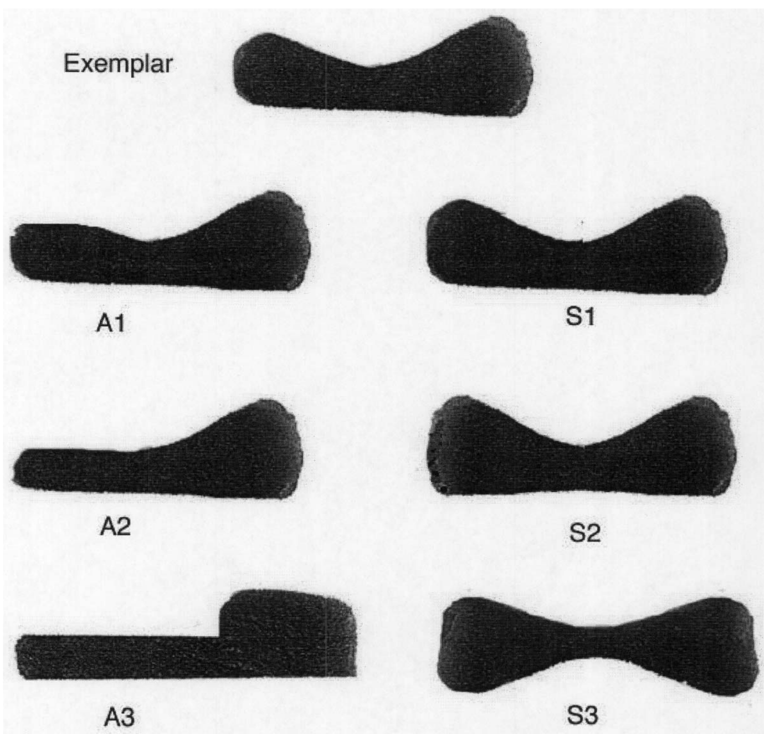

Fig. 4. The exemplar and the 6 test objects used in Experiment 2.

of one hand and then setting it on the table. All other aspects of the procedure and design were identical to Experiment 1.

3.2. Results and discussion

Fig. 5 shows the results from the forced-choice procedure; again, performing an action but not watching an action being performed altered children's judgments of shape. In the action conditions, children favored the symmetric object when they had moved the exemplar symmetrically about its center but not when they had acted on the exemplar in a way that treated the two sides differently, $F(1, 22) = 38.30$, $p < .001$. The preference for the shape congruent with the action also increased with the magnitude of stimulus difference between the test objects and the exemplar, $F(2, 44) = 3.48$, $p < .04$. There were no differences between the three no-action conditions; in all three conditions, there was a preference for the more symmetric test object in each pair and this preference increased with the greater symmetry and asymmetry of the test objects to the exemplar, $F(2, 44) = 5.45$, $p < .01$. This result may indicate a general baseline preference for symmetrical over asymmetrical forms (see also Rock, 1973).

Fig. 6 shows the results from the yes–no procedure; again the finding is that action alters children's categorizations of shape. In the action conditions, children said "yes" the name applies more to the symmetric test objects when they had moved the exemplar symmetrically with two hands, but said "yes" the name applies more to the asymmetric test objects when they had held one part of the exemplar and moved it with one hand, $F(1, 22) = 25.93$, $p < .001$. Children also said "yes" to the test objects less different in overall shape to the exemplar, $F(2, 44) = 13.70$, $p < .001$. The no-action conditions did not differ from one another; in all three conditions, children said "yes" most to objects that differed less from the exemplar in overall shape than to those that differed more, $F(2, 66) = 19.78$, $p < .001$, and to symmetric more than asymmetric test objects, $F(1, 66) = 5.30$, $p < .05$.

Again, under both task procedures, action changes the range of shapes children judge to be members of the same category, but watching someone else act on and move the objects in the same way does not.

4. General Discussion

Theories of object recognition (both structural and view-based) are for the most part theories of static object recognition (see Lui & Cooper, 2003). Yet how we act on objects is intimately related to their shapes, and perhaps even defining of them. At the very least, these results show that action has a strong influence on the range of shapes 2-year-olds take as being similar and appears to do so by defining axes of elongation and symmetry. Because elongation and symmetry are crucial to shape processing more generally, this raises the possibility that action molds processes fundamental to object recognition. The critical open question is the mechanism that underlies the observed effects. Four possibilities are outlined.

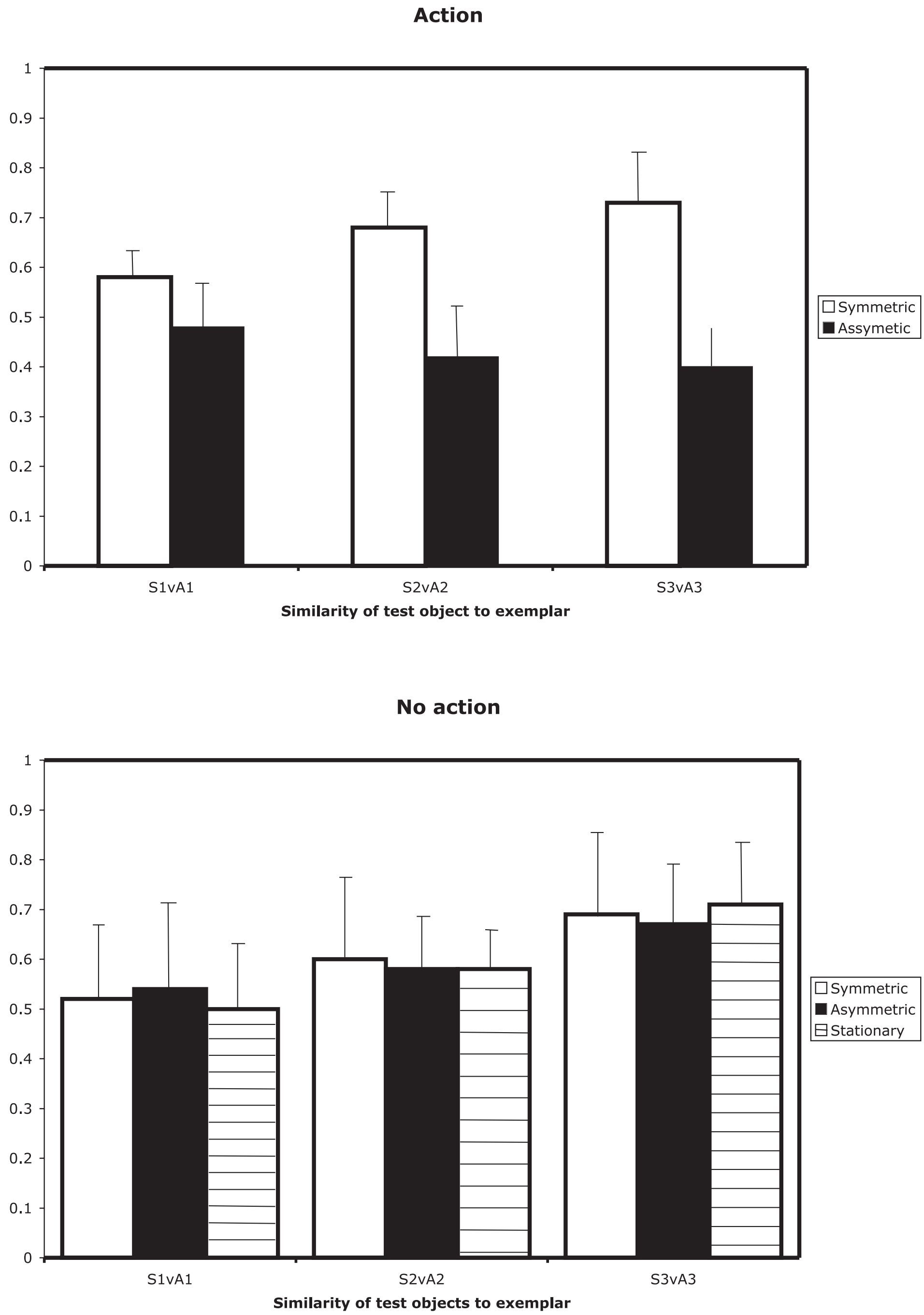

Fig. 5. Mean proportion choices of the more symmetric test object as a function of the similarity of the contrasting test objects to the exemplar in the two Action and three No Action conditions in the Forced-Choice procedure in Experiment 2.

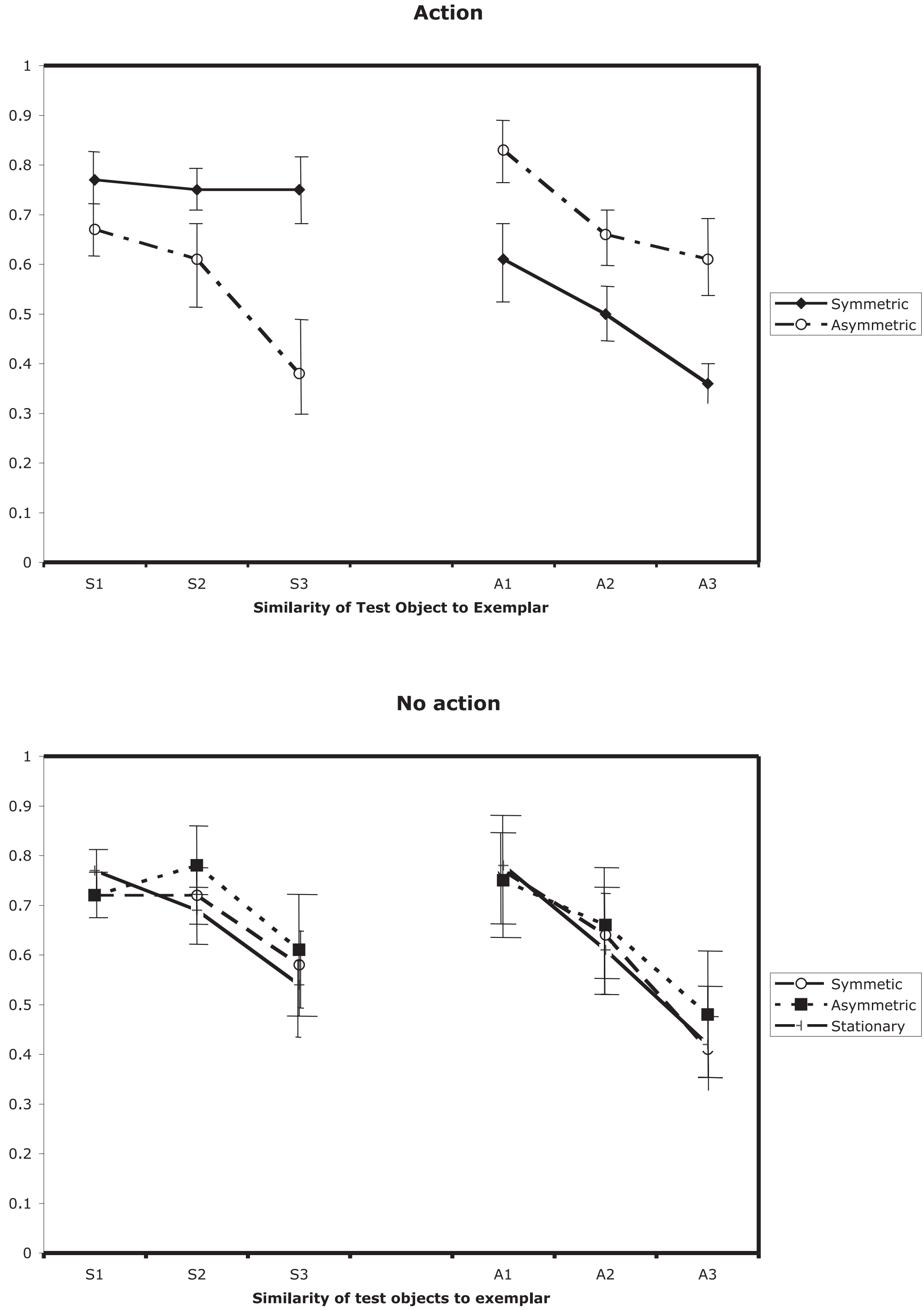

Fig. 6. Mean proportion "yes" responses as a function of the similarity of the test object to the exemplar in the two Action and three No Action conditions in the "yes/no" procedure in Experiment 2.

4.1. Associations between action and shape

There are physical and biological constraints on how we can hold and move objects of different shapes and thus likely associations between symmetry, elongation, and paths of movement. Related to this idea is Morikawa's (1999) proposal that adults' biases to perceive movement parallel to an object's long axis derive from a regularity in the world, that objects in general move on paths parallel to their long axis. However, one can think of obvious exceptions; people, for example, move orthogonally to their long axis. Still, people's manual movements of objects (rather than how objects move on their own) may well be systematically related to shape in ways consistent with these results. Further, if the relevant associations are specifically between motor planning (or the perceived feel of a movement) and shape, then such a regularity might explain why merely watching an action is insufficient to create a measurable change in shape judgments.

4.2. Iconicity between action and perceived shape

Felt-body movements may also map to shapes by dint of their similarity. Certainly, the pervasiveness of iconic gestures in human communication suggests cross-modal correspondences between manual movement paths and aspects of visual shape (Kendon, 1980; Kita, 2000). Thus, in these experiments, children might have chosen (or responded "yes" to) the test object that was most globally similar to the trajectory of its motion. Again, if the relevant trajectory were based on felt-body position and not on the visual path of movement, then an effect of action, but not of watching action, would be expected.

4.3. Role for visual motion

The visual information we receive about objects varies systematically with our actions on those objects. Thus, it is possible that the effect of action on shape judgments is mediated through effects of visual motion on shape. For example, the moving edges of a form at one moment in time may blend with the activation from that edge at a preceding moment, causing blurring and perceived extension at that edge. A number of psychophysical studies show a variety of other interactions between motion and shape perception that may provide a precedent for this idea (e.g., Tse & Logothetis, 2002; Watanabe, 1997). A role for visual motion seems to be contradicted by the finding that doing and not merely watching was required to alter children's shape judgments. One possibility, however, is that young children's visual attention to the object is more focused when they are acting rather than watching another do the action. Thus it may be premature to rule out this class of mechanisms.

4.4. Direct effects of action on shape processing

Finally, it is also possible that there is some form of lower level recruitment by the motor system of the visual processes central to shape perception. The extant evidence indicates that dynamic visual events exert a direct online influence on motor control (e.g., Grezes & Decety, 2001). The question raised by these results is whether that influence might flow in the opposite direction as well. Emerging evidence suggests exuberant multimodal connections in young brains that are pruned with development (Huttenlocher, 2002; Johnson & Vecera, 1996; Maurer & Mondloch, in press; Thelen & Smith, 1994). If this is so, action might well activate visual brain regions in young children and play a role in the development of those regions.

Clearly more experiments are needed to disentangle and elucidate possible mechanisms. The importance of these results—and the candidate mechanisms—concerns their potential developmental consequences in the context of children's everyday and repeated interactions with objects. Young children habitually act on categories of objects in systematic ways. These repeated actions may be expected to change how aspects of shape are processed and remembered. The implication of this is clear: If we did habitually use chairs to tame lions rather than to sit on, we would represent their shapes differently than we do now.

Acknowledgments

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